Lecture 12 – Oxygen deficiency in the geological record

- Biomarkers and paleoenvironments
  - Plankton ecology
  - Redox changes and water column stratification
  - Sea-surface temperature
- Mechanisms for ocean deoxygenation
- Examples of oceanic anoxic events (OAEs)
  - Cretaceous OAE-2 (Cenomanian-Turonian, ~93.5 Ma)
  - Permian-Triassic mass extinction (~252 Ma)

Global marine primary production - sized

Microphytoplankton >20 μm
Diatoms & Dinoflagellates

Nanophytoplankton 2-20 μm
Prymnesiophytes

Picophytoplankton <2 μm
Cyanobacteria

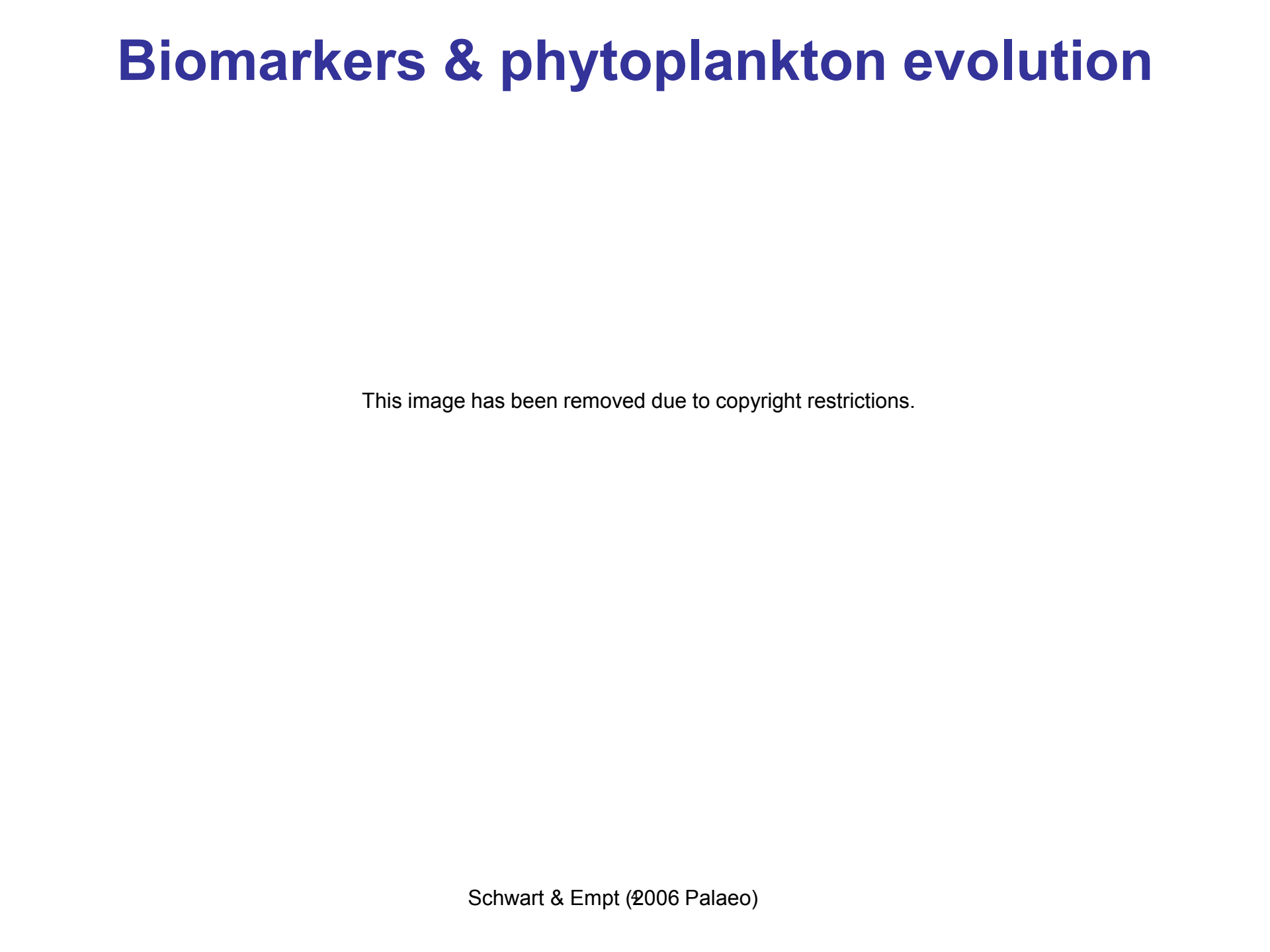
Uitz *et al*. (2010 Global Biogeochemical Cycles)

Evolution of modern marine phytoplankton

These images have been removed due to copyright restrictions.

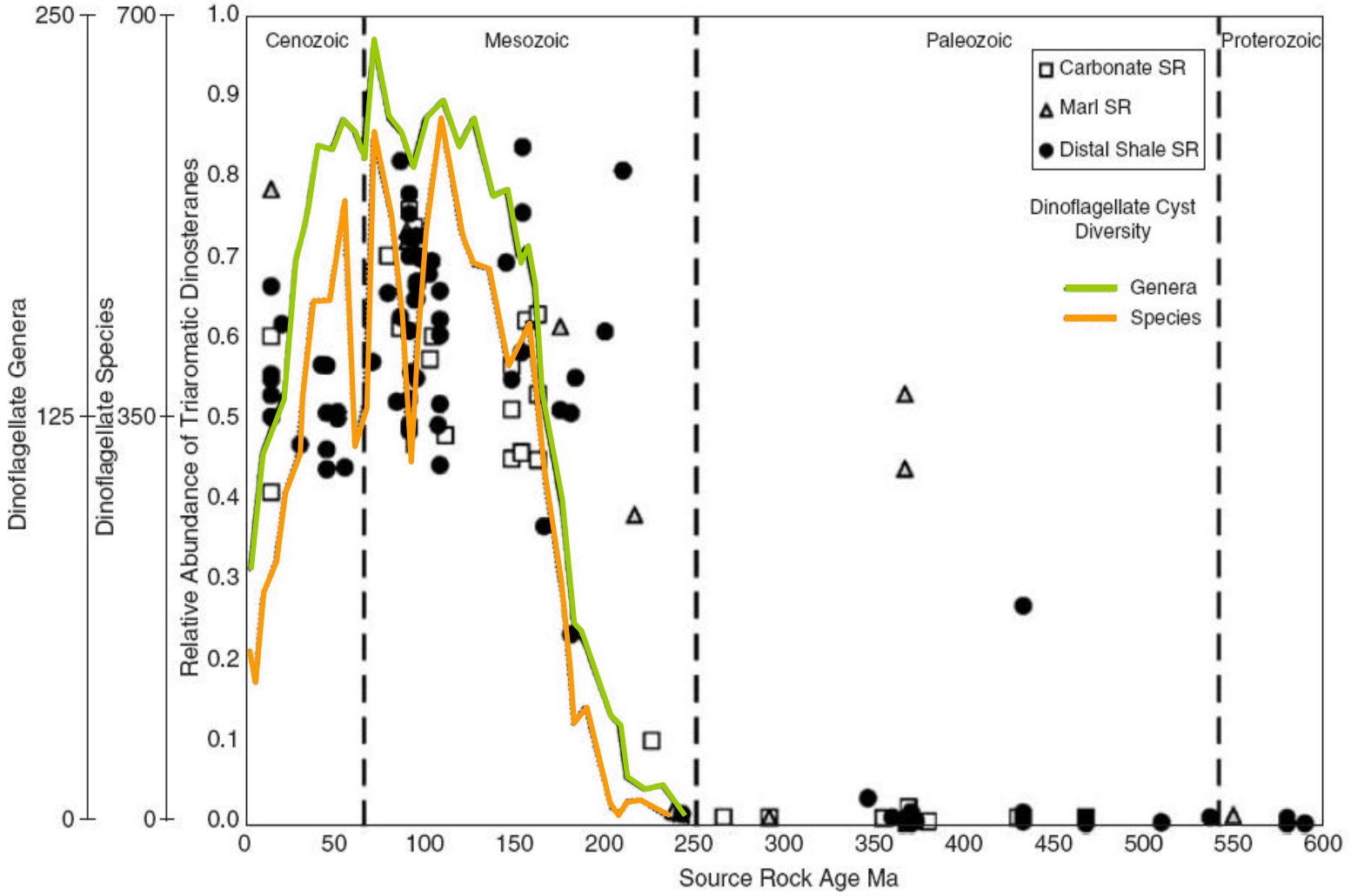
Katz *et al*. (2005 Annu. Rev. Ecol. Evol. Syst)

Biomarkers & phytoplankton evolution



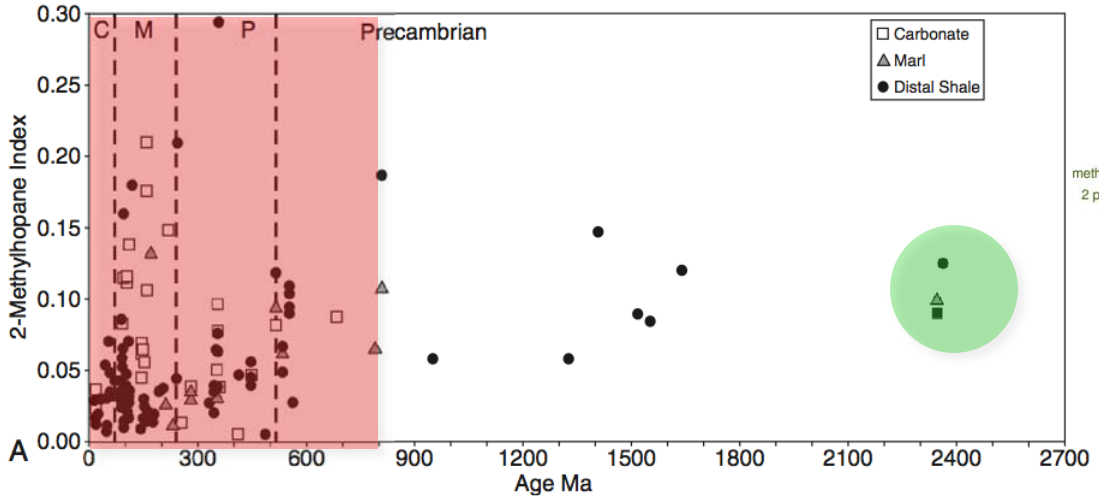
Schwart & Empt (2006 Palaeo)

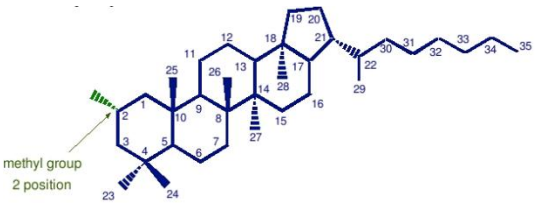
Biomarkers & phytoplankton evolution

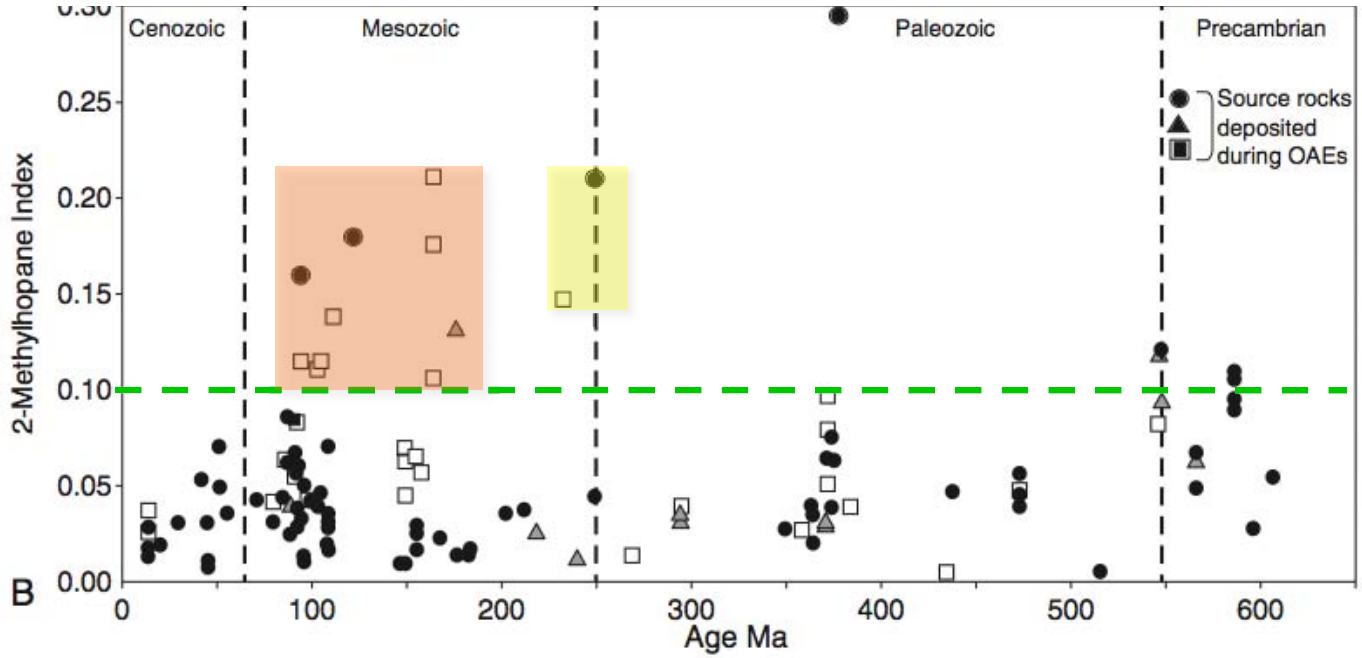


After Knoll et al. (2007)

Biomarkers for cyanobacteria







After Knoll *et al*. (2007)

Proxies for water column stratification and oxygen deficiency

Tetrahymanol & Gammacerane

Miocene Gessoso-solfifera Formation

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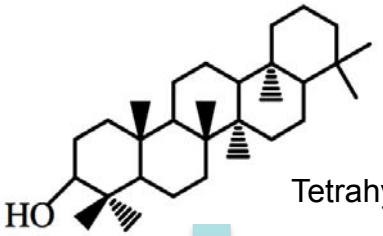
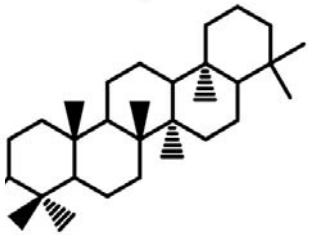
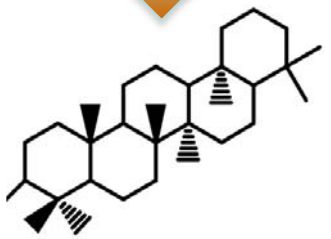


Tetrahymanol



ıylthiogammacerane



ıacerane

Sinninghe Damste *et al*. (1995 GCA)

Lycopane

Mid-Cretaceous (Cenomanian-Turonian) OAE

Surface sediments
Arabian Sea

Sinninghe Damste *et al*. (2003, EPSL)

Preservation of extended side-chain hopanes

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Köster *et al*. (1997, GCA)

Anaerobic ammonium oxidation (anammox)

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$

Lipids with linear concatenated cyclobutane moieties

[3]-ladderane 2-alkyl glycerol monoether

[5]-ladderane FAME

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[3]-ladderane FAME

Sinninghe Damste et al. (2005, FEBS)

Markers for nitrogen cycling

archaea

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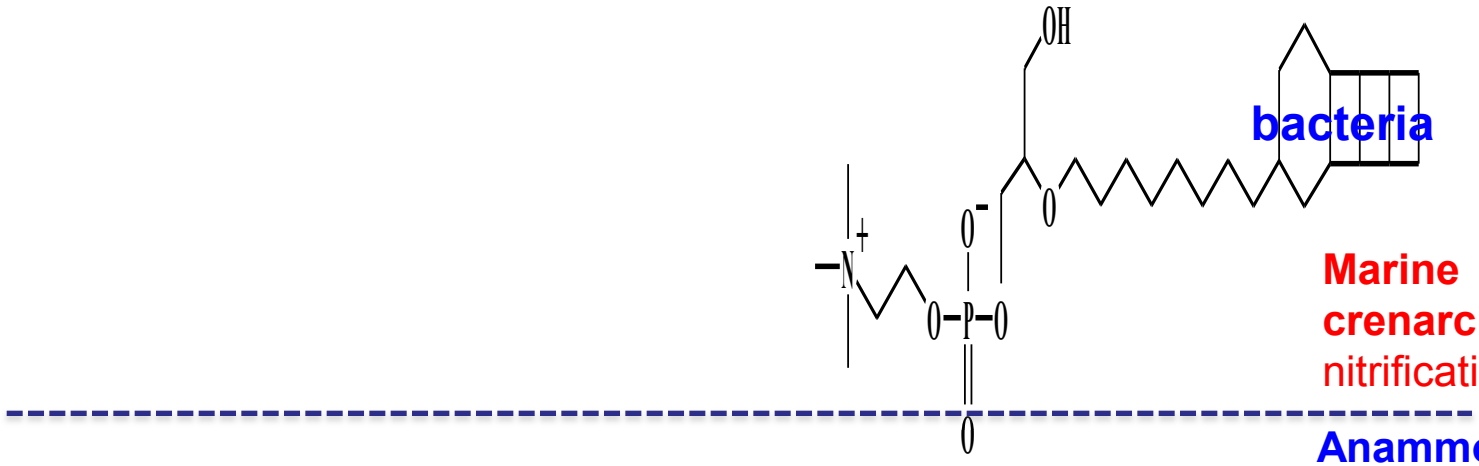


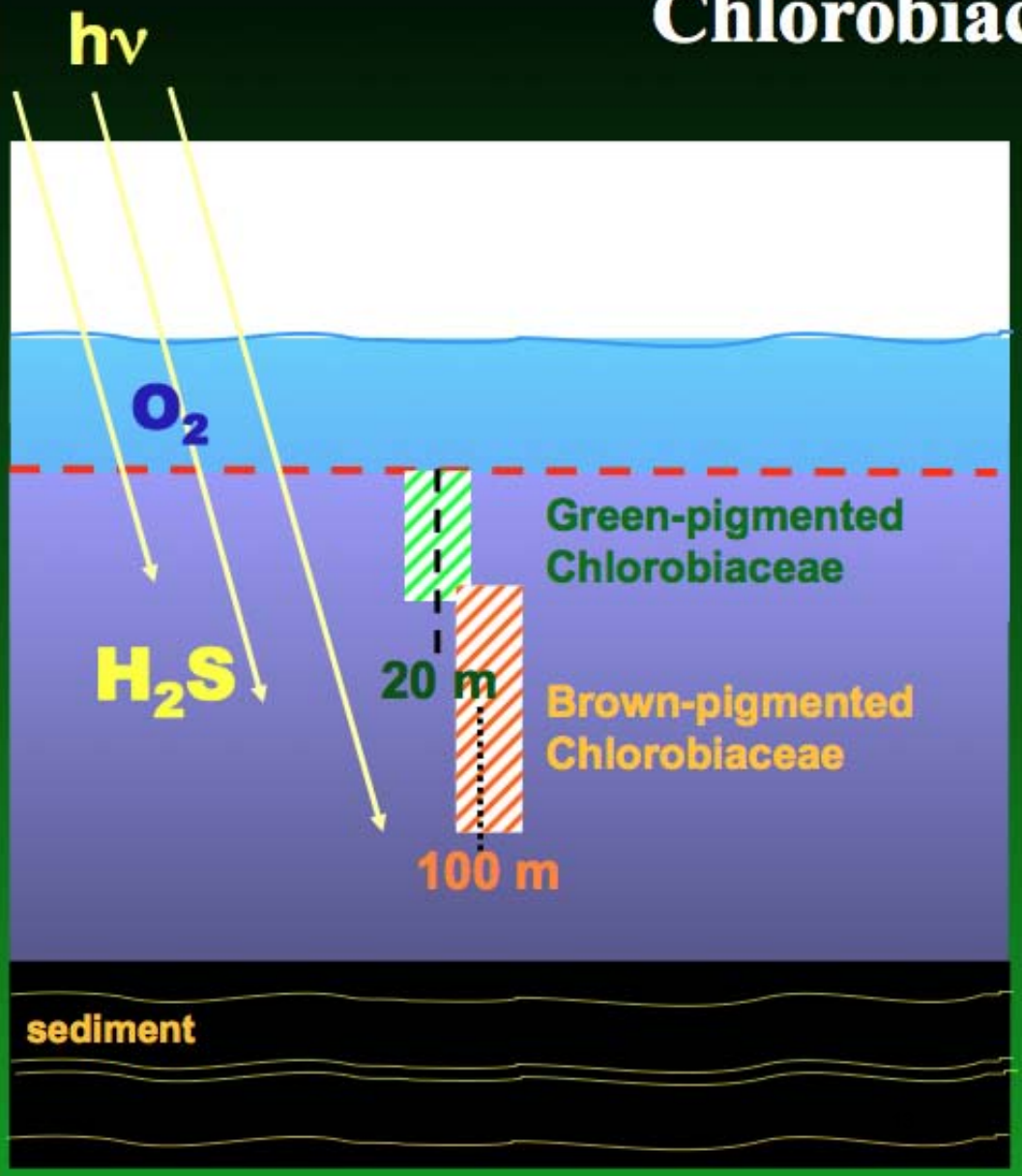
bacteria

Marine crenarchaea: nitrification

Anammox bacteria: Anaerobic oxidation of ammonium

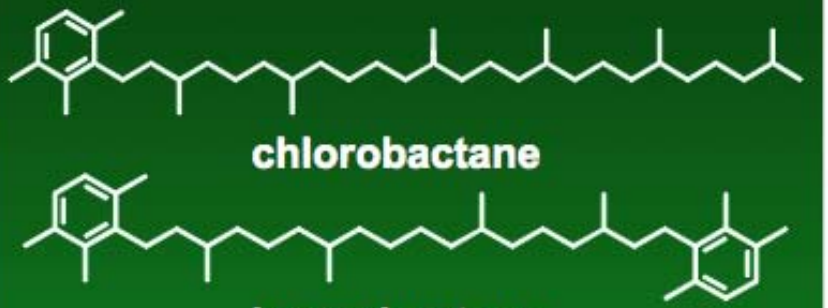
Green sulfur bacteria

Chlorobiaceae



Biomarkers of Chlorobiaceae

Photic zone euxinia



chlorobactane

isorenieratane

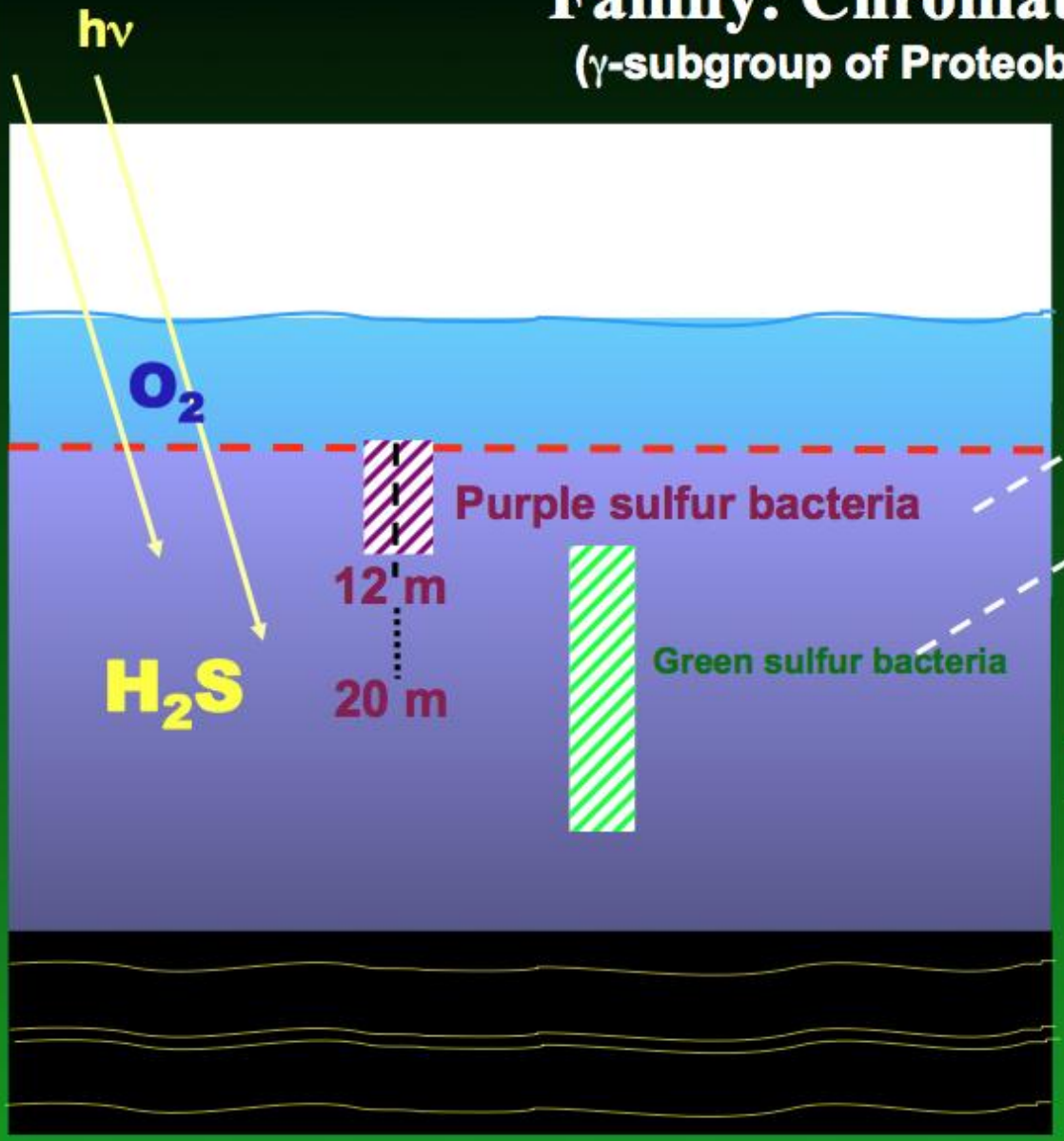
Source: Roger Summons

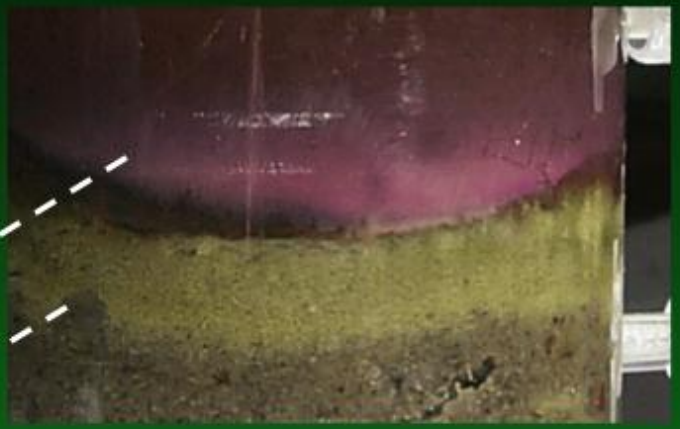
Summons *et at.*, 1987

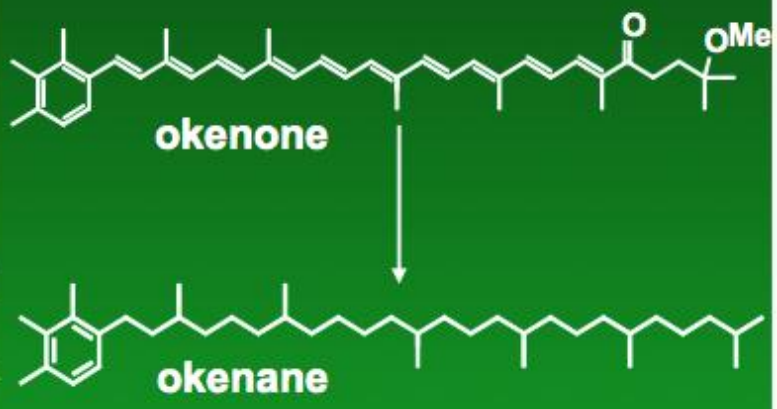
Purple sulfur bacteria

Family: Chromatiaceae

(γ-subgroup of Proteobacteria)







Source: Roger Summons

The Black Sea – water chemistry

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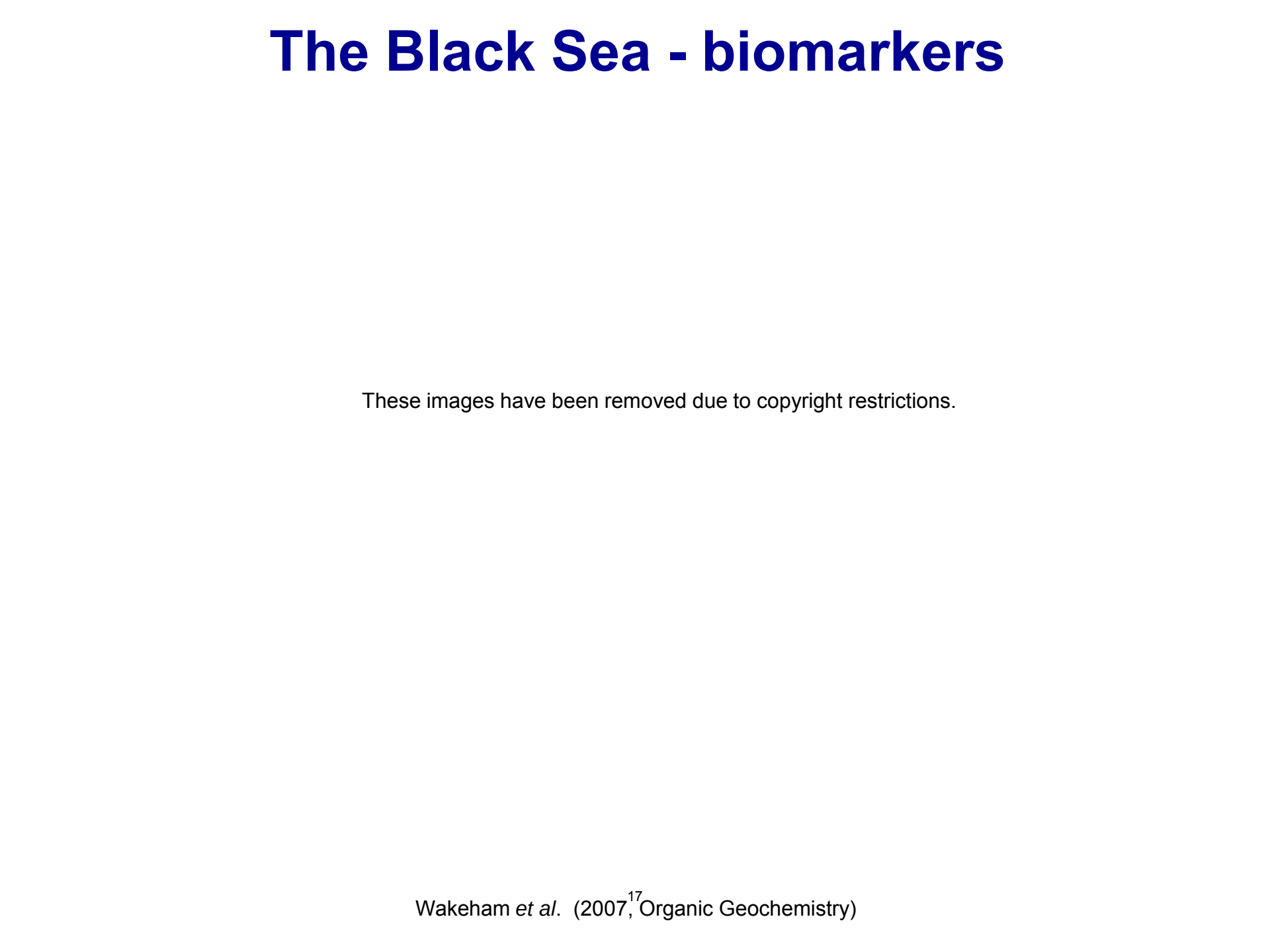
Wakeham *et al*. (2007, Organic Geochemistry)

The Black Sea - biomarkers

These images have been removed due to copyright restrictions.

Wakeham *et al*. (2007, Organic Geochemistry)

The Black Sea - biomarkers



Wakeham *et al*. (2007,[17] Organic Geochemistry)

The Black Sea - biomarkers

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Wakeham *et al*. (2007, Organic Geochemistry)

IPLs follow water column stratification: Black Sea

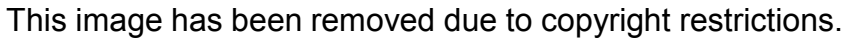
Oxic: phototrophs

Suboxic: anoxygenic phototrophs
Ammonium oxidizing crenarchaea

Anoxic: sulfate-reducing bacteria, unknown anaerobic bacteria

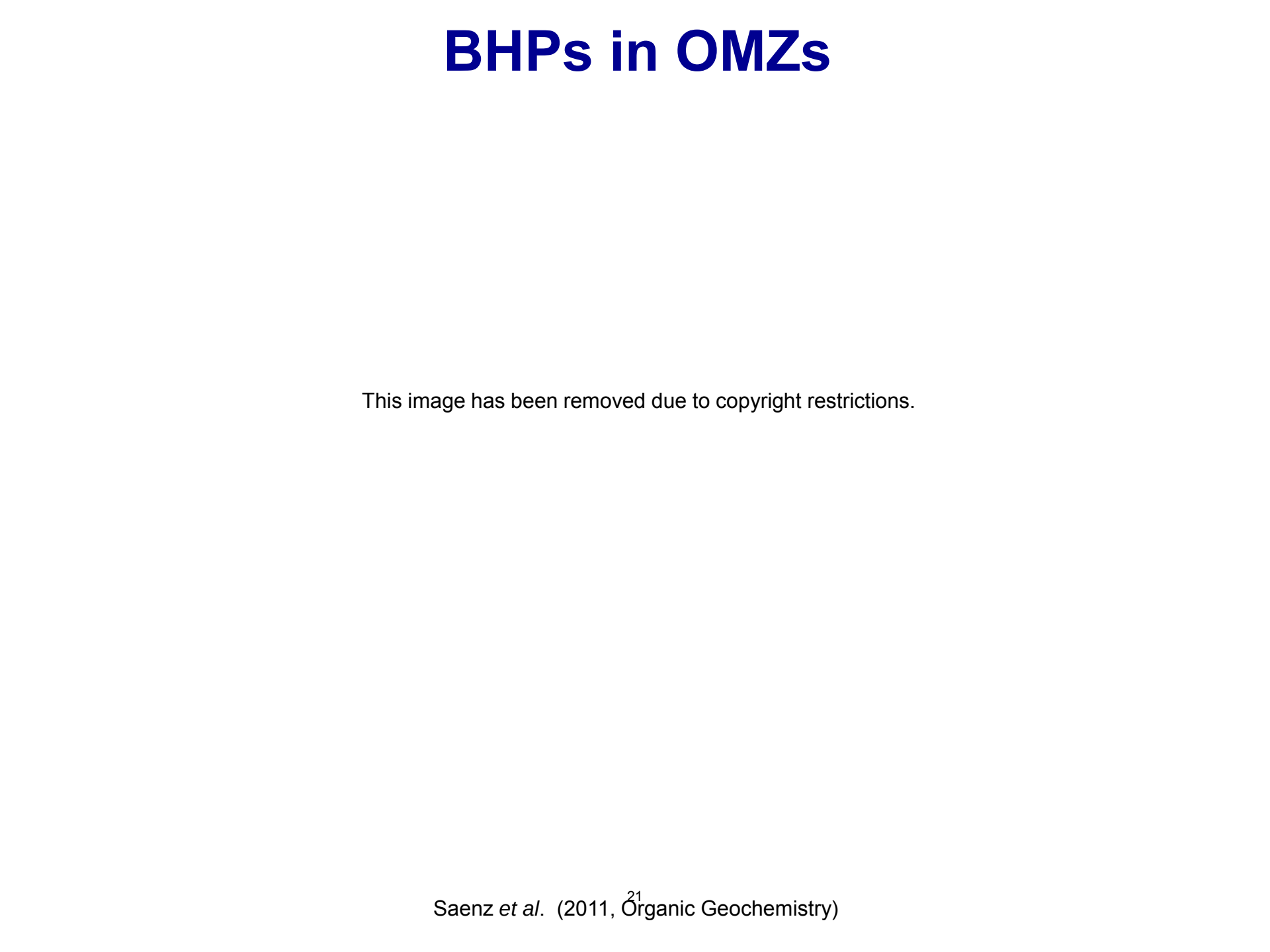
Schubotz et al., EM (2009)

BHPs in OMZs



Saenz *et al*. (2011, Organic Geochemistry)

BHPs in OMZs



Saenz *et al*. (2011, Organic Geochemistry)

Proxies for Sea Surface Temperature

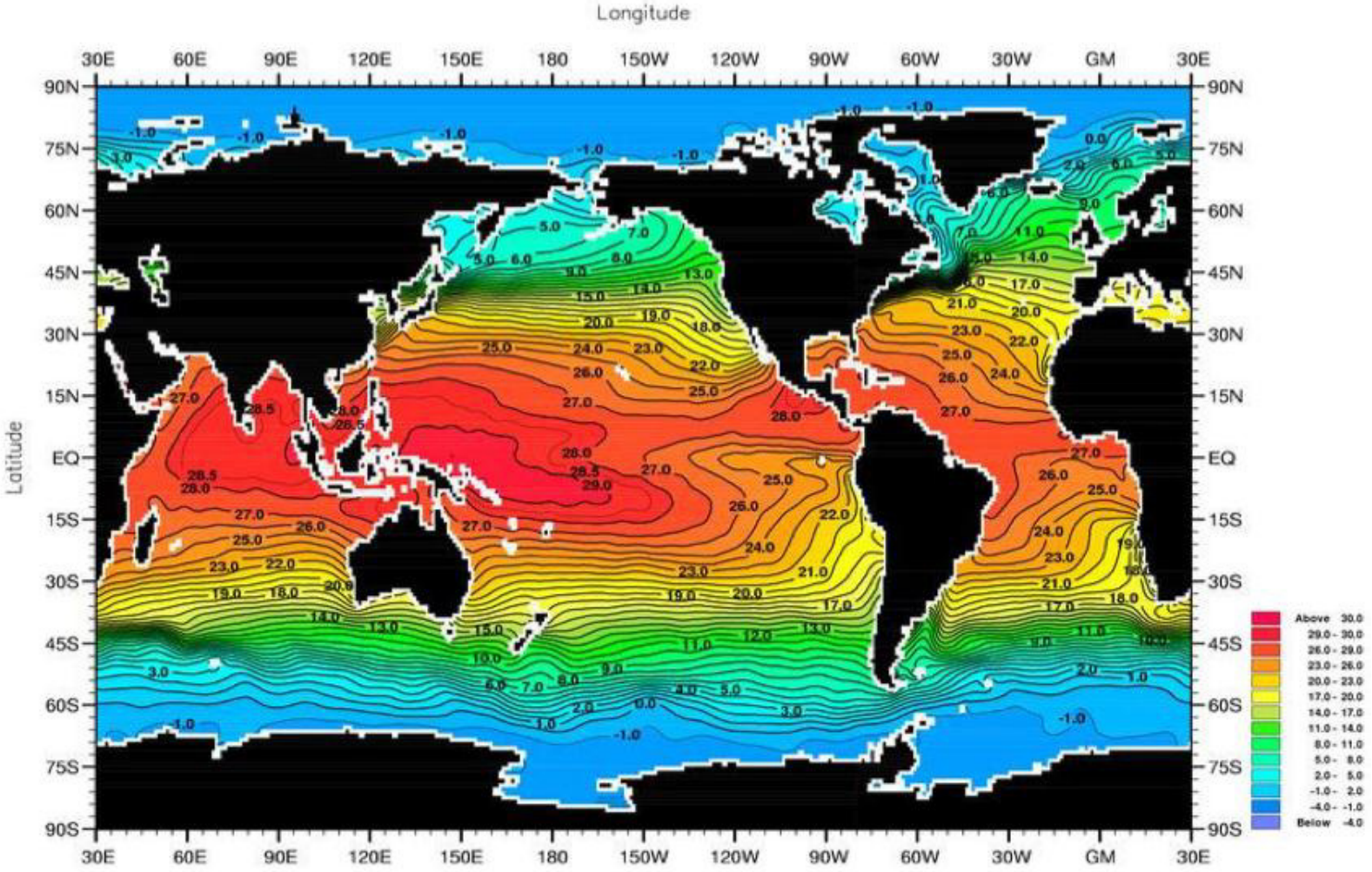


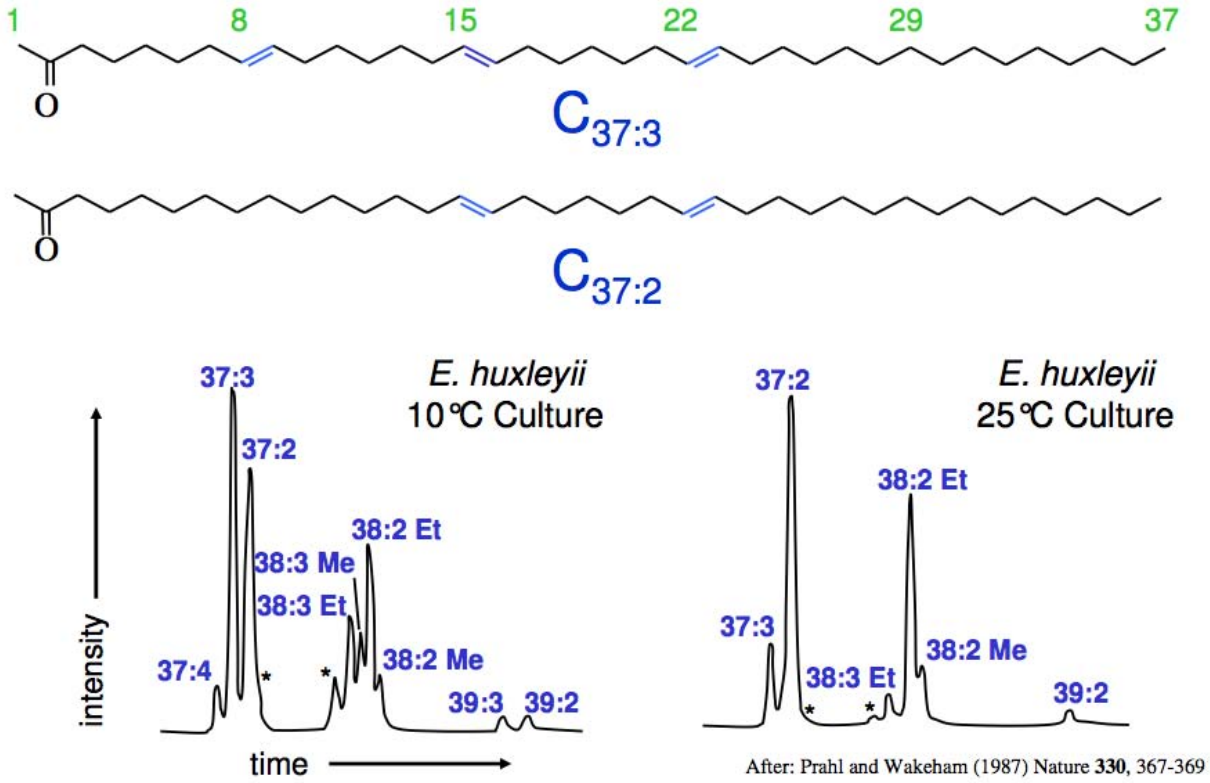
Fig. A2-1. Annual mean temperature (℃) at the surface.

Minimum Value= -1.93 Maximum Value= 29.93 Contour Interval: 1.00

http://www.nodc.noaa.gov

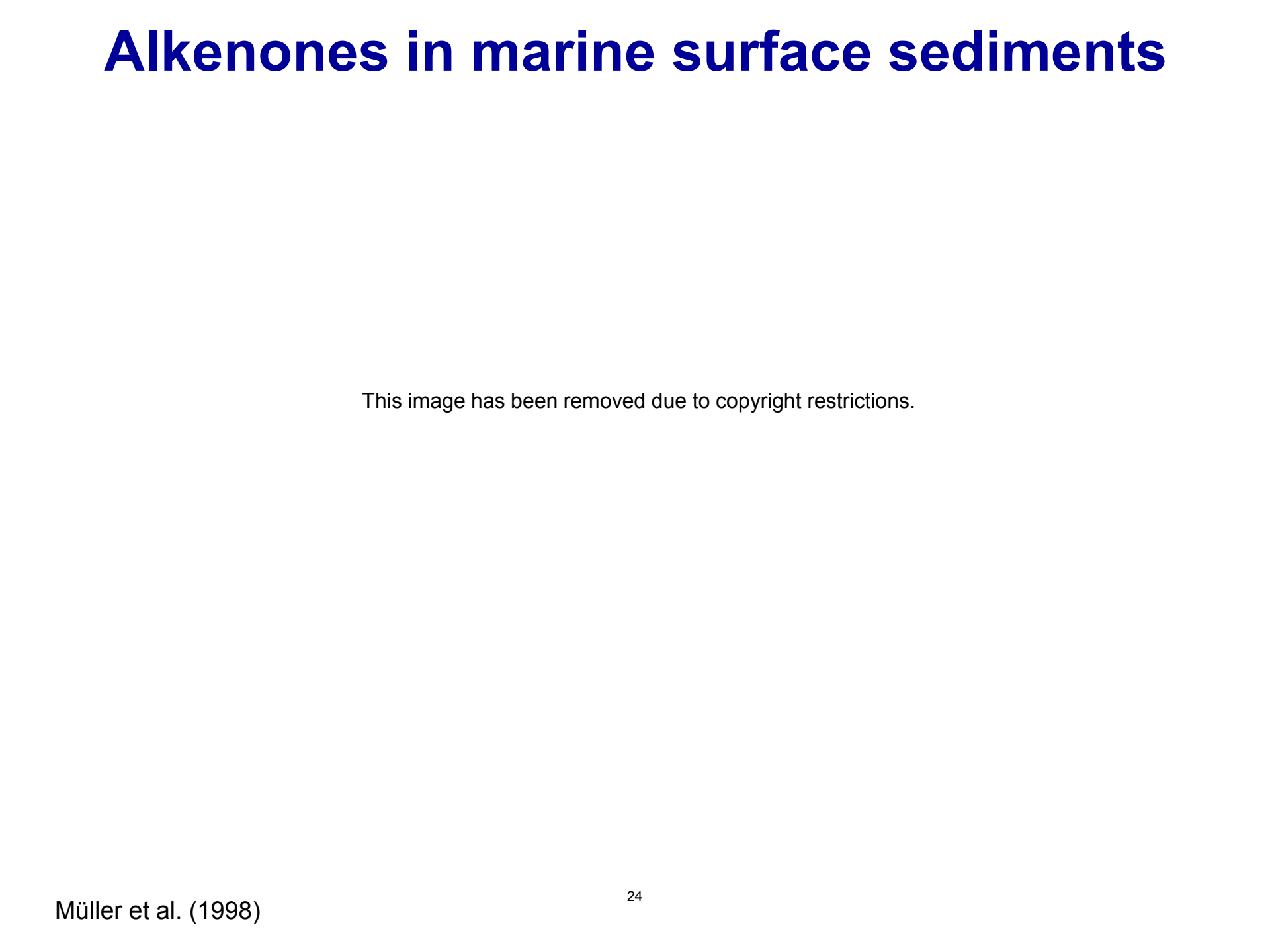
Image courtesy of NOAA.

Temperature proxies: Long-chain Alkenones



After: Prahl and Wakeham (1987) Nature **330**, 367-369

Alkenones in marine surface sediments



Müller et al. (1998)

Sea Surface Temperature: TEX_{86}

$$TEX_{86} = \frac{([III] + [IV] + [V'])}{([II] + [III] + [IV] + [V'])}$$

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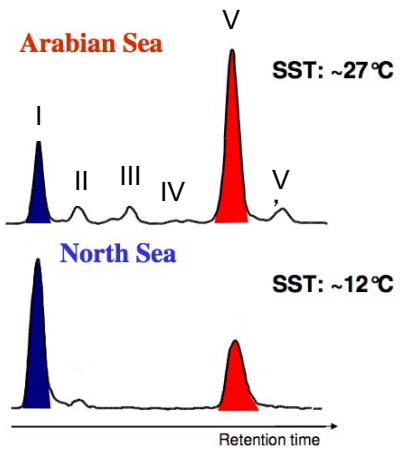


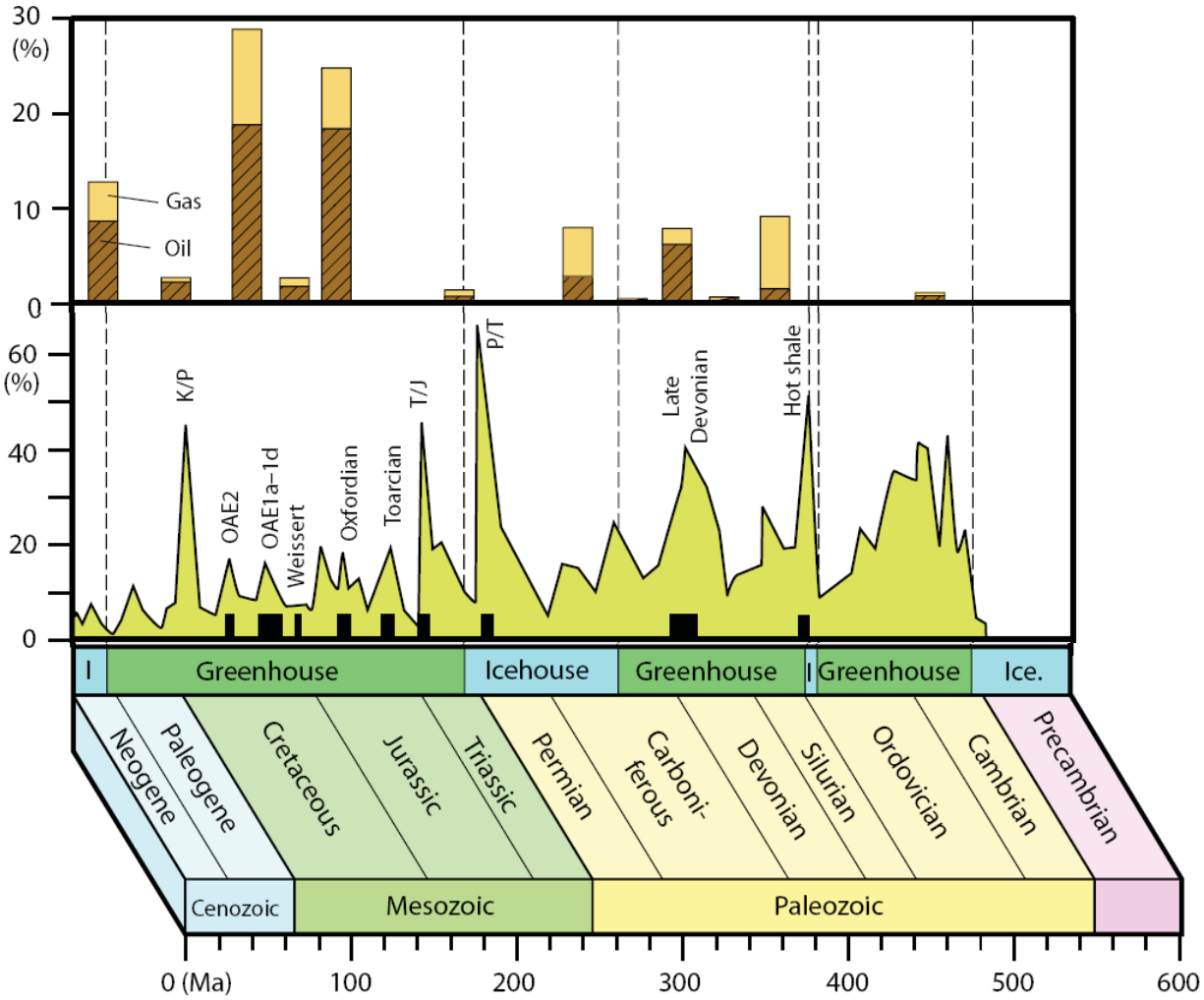
Schouten *et al.* (2002, EPSL); Kim *et al.* (2008, GCA)

Oxygen deficiency in the past

OAEs, extinctions & black shales

(G) Percent of world's original petroleum reserves generated by source rocks (Klemme and Ulminshek,1991)

(F) Percentage extinction of marine genera (Raup and Sepkoski, 1986) and major Oceanic Anoxic Events



After Takashima *et al*. (2006)

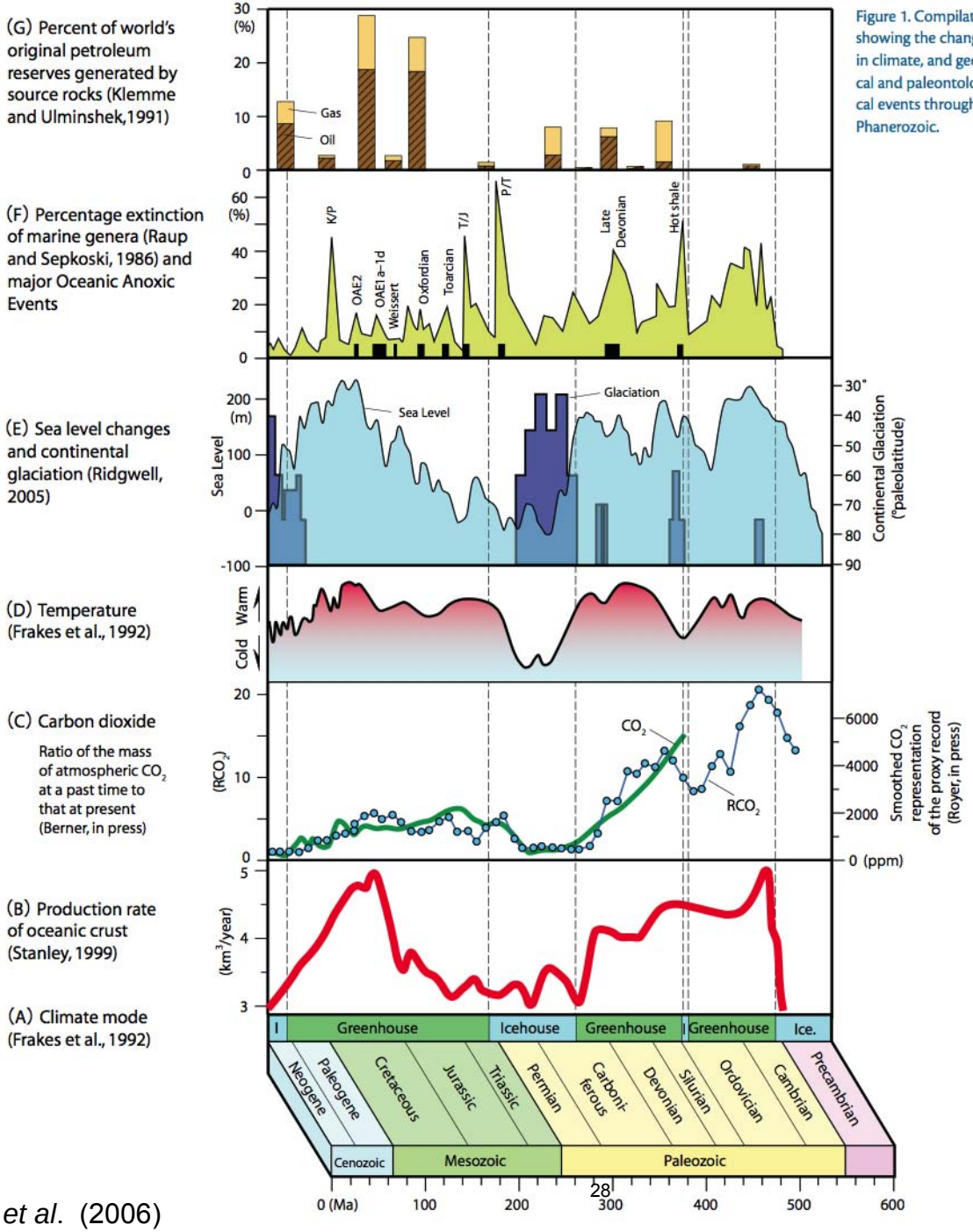


Figure 1. Compilation showing the changes in climate, and geological and paleontological events through the Phanerozoic.

After Takashima *et al*. (2006)

Ocean anoxia & black shale formation

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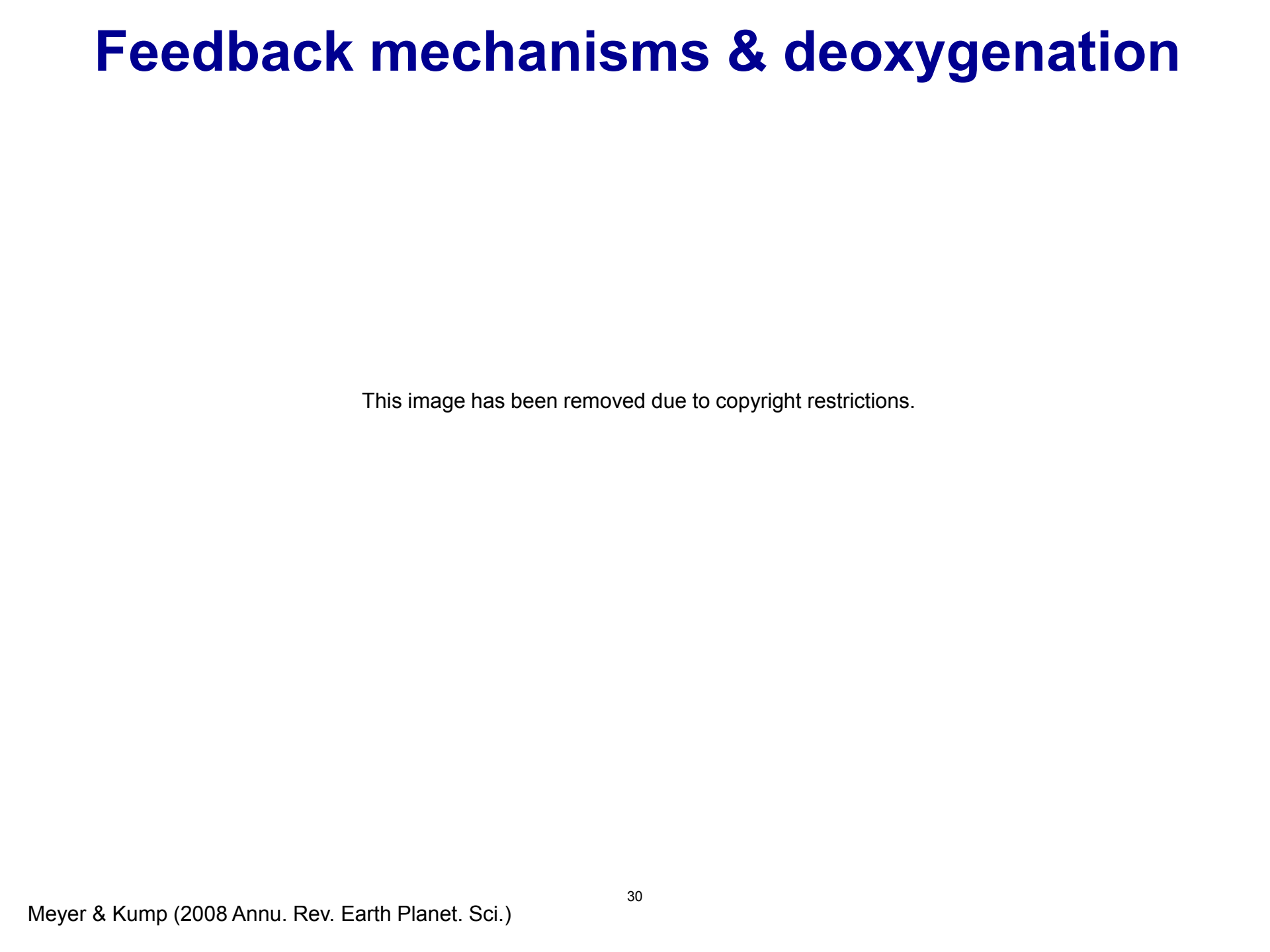
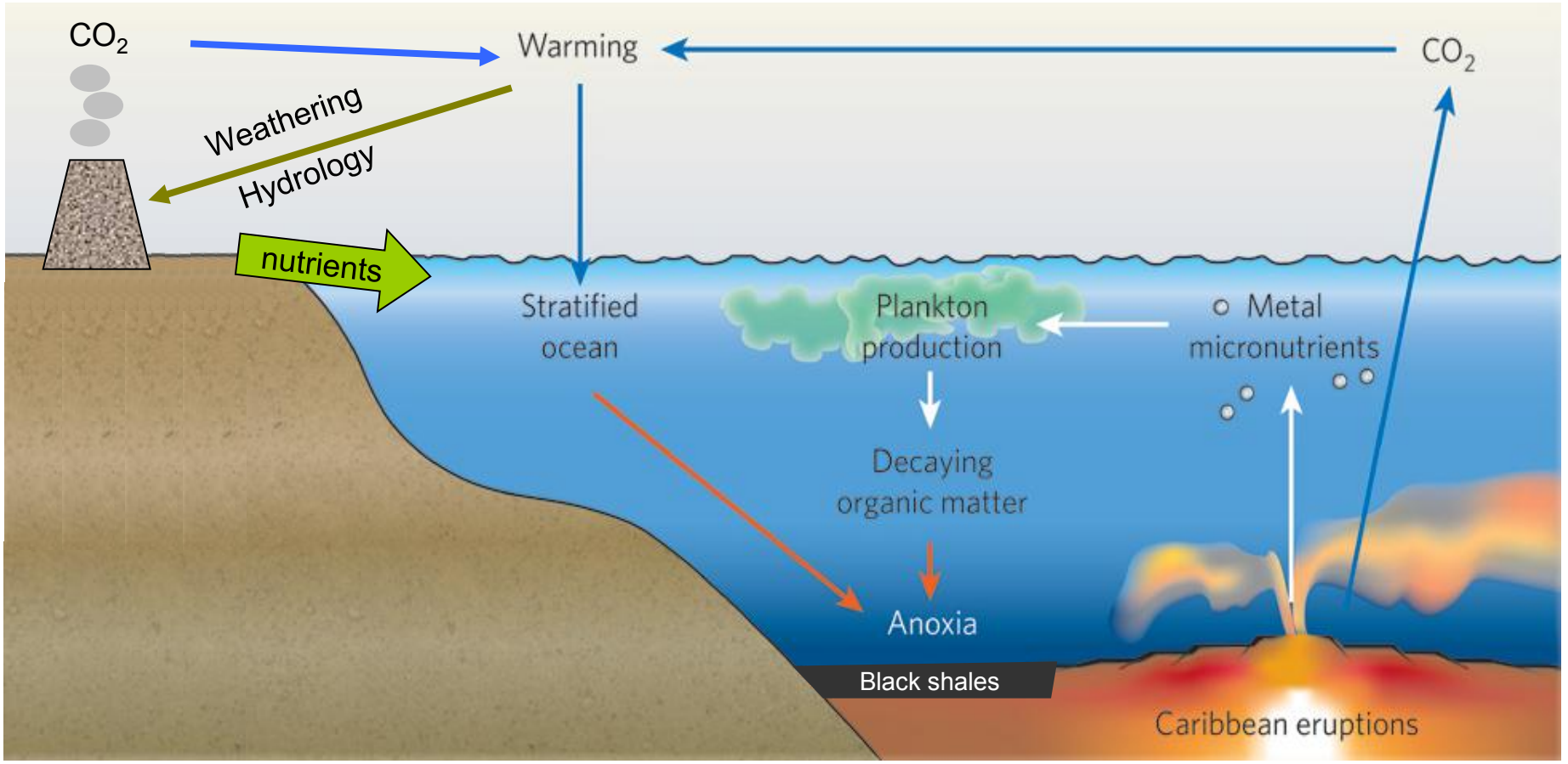
Takashima *et al*. (2006, Oceanography)

Feedback mechanisms & deoxygenation



Meyer & Kump (2008 Annu. Rev. Earth Planet. Sci.)

Mechanisms for ocean anoxia: Volcanism



After Bralower (2008, Nature)
Turgeon & Creaser (2008, Nature)
Meyer & Kump (2008, Annu. Rev. Earth Planet. Sci)

Mechanisms for ocean anoxia: Orbital forcing

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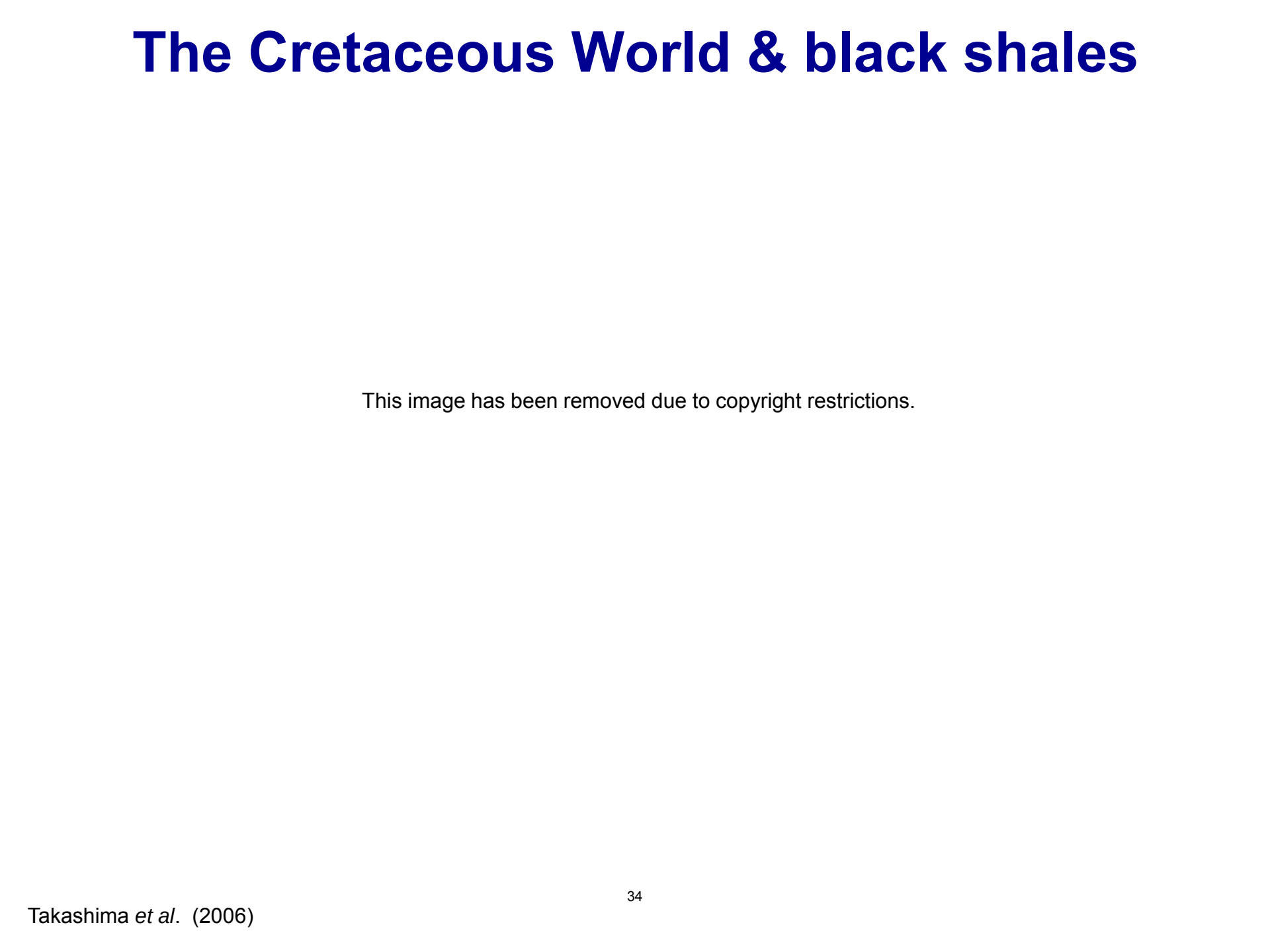
Zachos *et al*. (2001, Science)

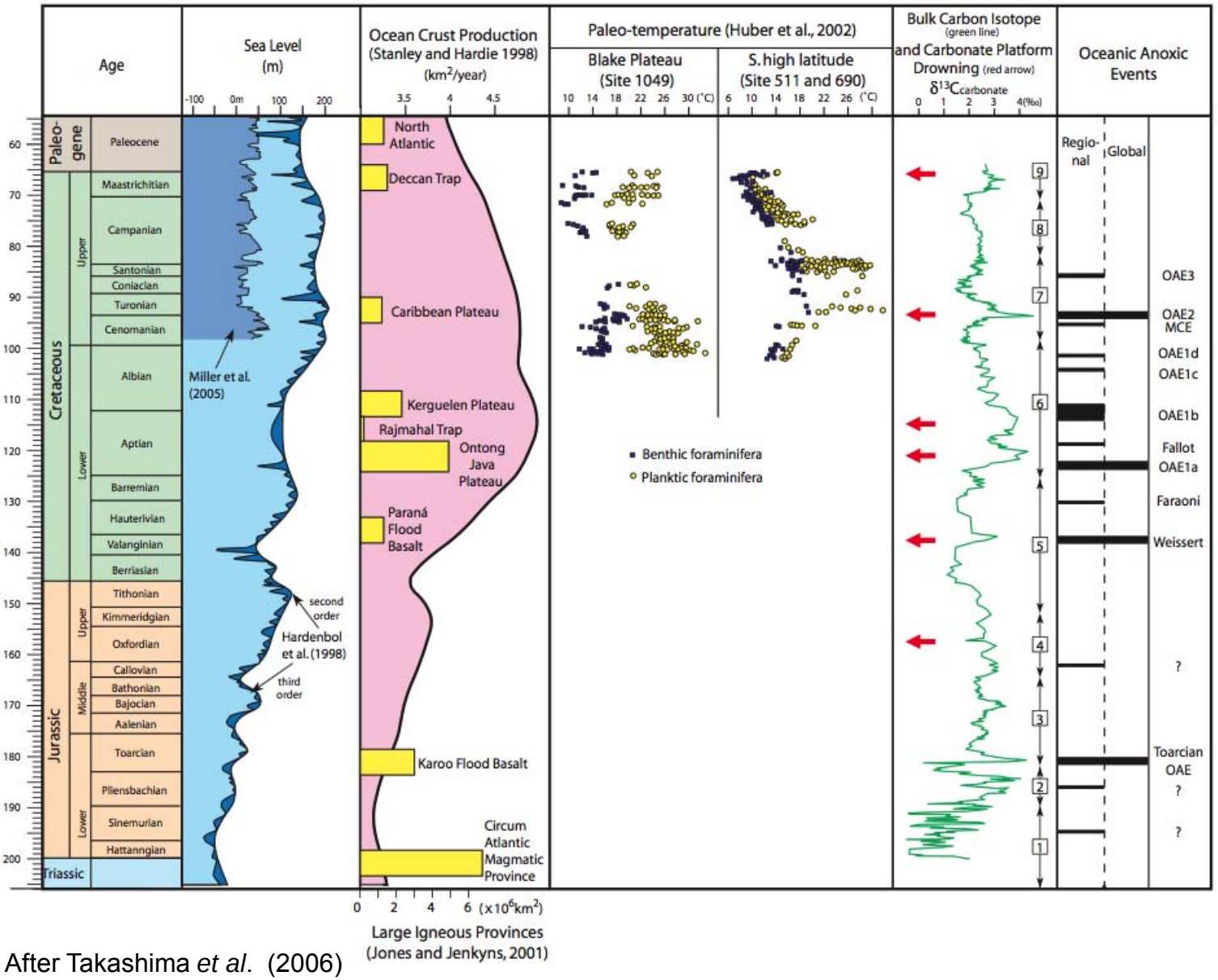
Oxygen deficiency in the past Cretaceous OAEs

The Cretaceous World & black shales



Takashima *et al*. (2006)

Oceanic Anoxic Events (OAEs)



After Takashima *et al*. (2006)

Major perturbation in the global climate – ocean system

Chemical and/or biological changes in the world oceans

Black carbon-rich shales from deep oceans to shealf seas

Enhanced productivity

Enhanced preservation of organic matter

Reduced circulation

Small latitudinal temperature gradient

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- Intense volcanism & high pCO_2
- Greenhouse climate & high sea surface temperatures
- Enhanced primary productivity
- Widespread anoxia and euxinia
- High burial of organic carbon
- Positive isotopic excursion

Takashima *et al*. (2006)

Cenomanian-Turonian OAE-2

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Foster *et al*. (2007 Paleoceanography)

Large Igneous Provinces (IPLs) and OAEs

Turgeon and Creaser (2008 Nature)

Cretaceous Sea Surface Temperatures

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Sinninghe Damste e*t al*. (2010)

Cyanobacteria & N_2 fixation

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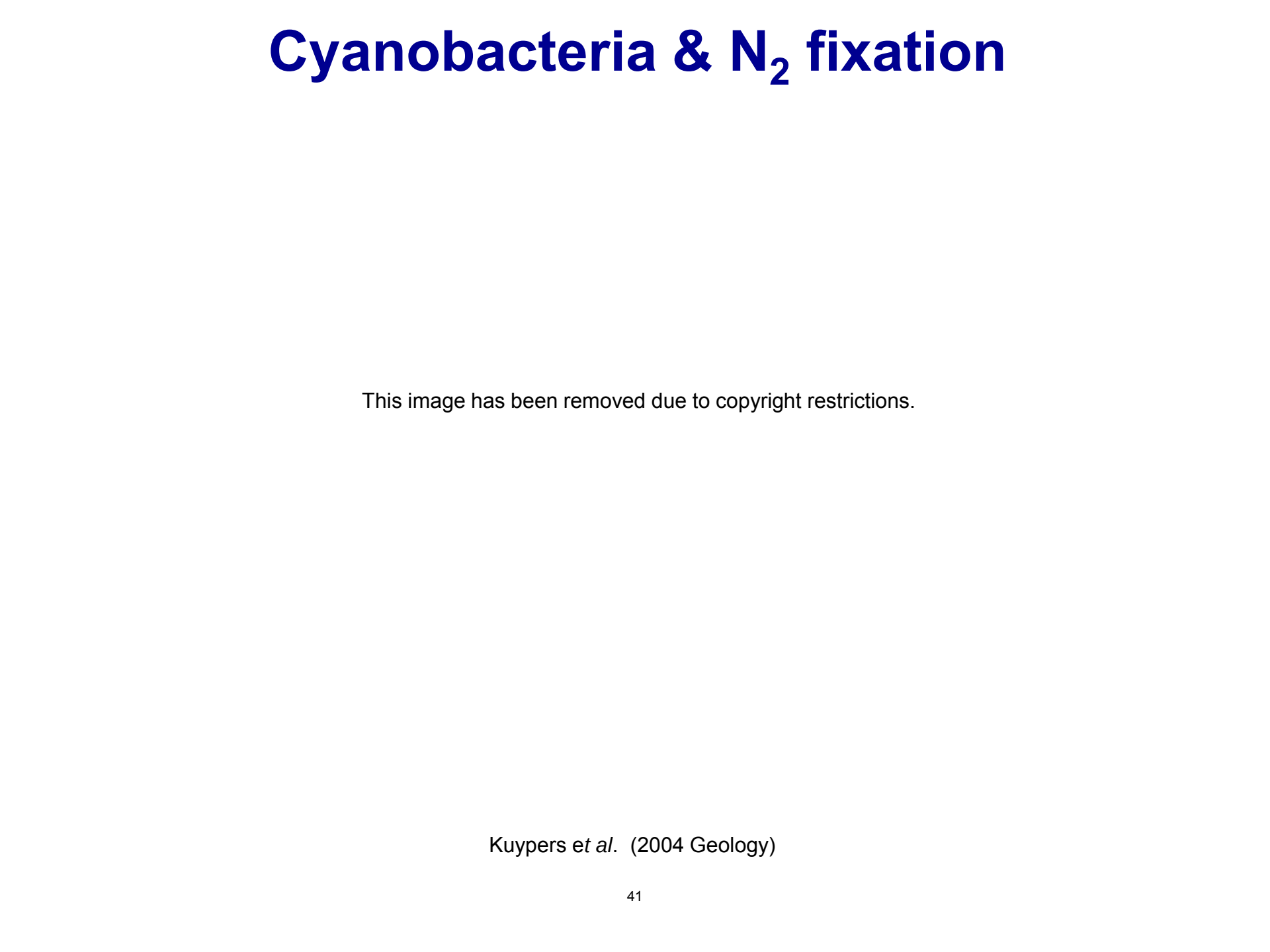
Kuypers e*t al*. (2004 Geology)

Cyanobacteria & N_2 fixation



Kuypers e*t al*. (2004 Geology)

Massive expansion of Marine Archaea

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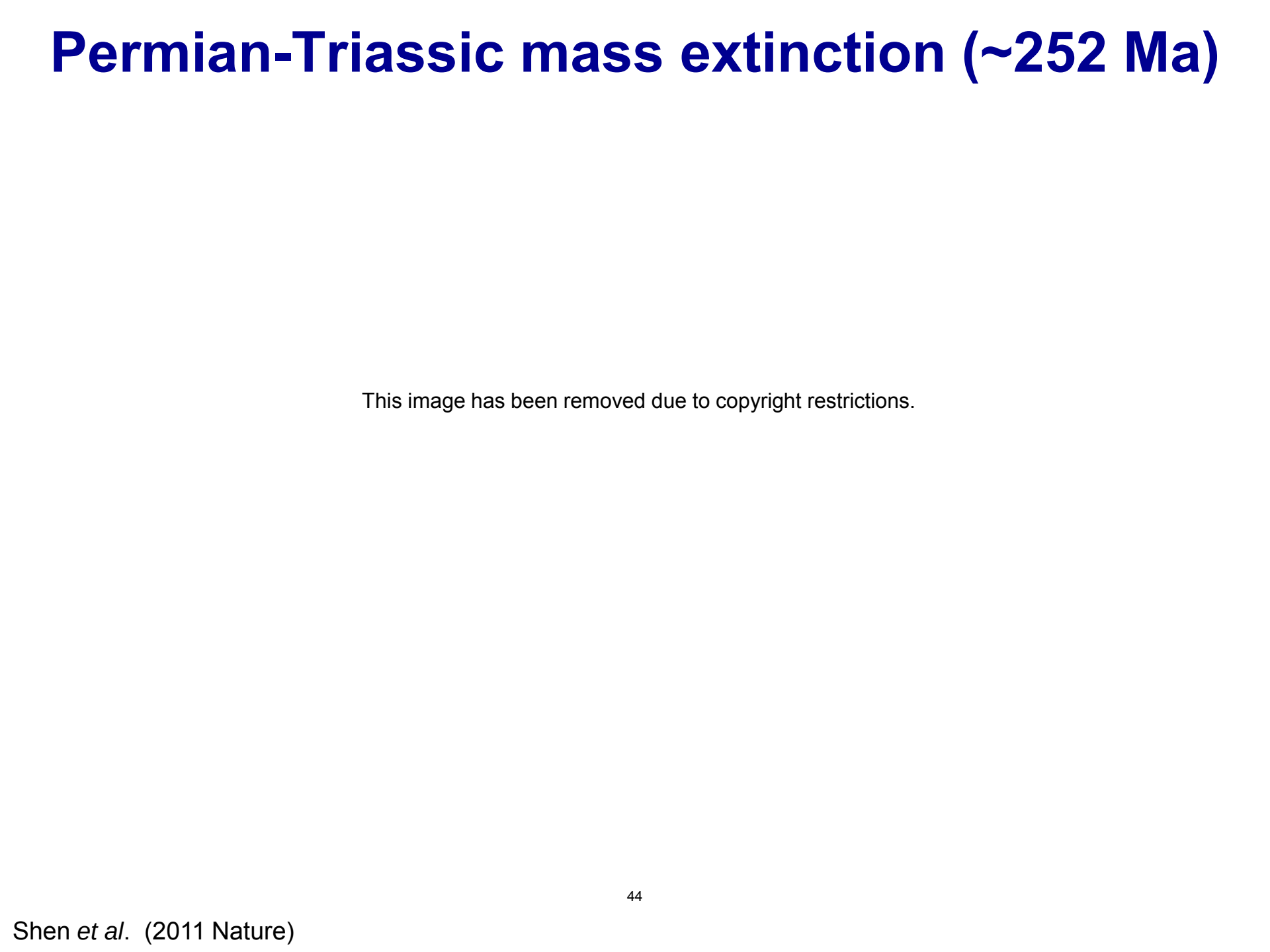
Kuypers e*t al*. (2001)

Oxygen deficiency in the past Permian-Triassic boundary

Permian-Triassic mass extinction (~252 Ma)



Shen *et al*. (2011 Nature)

Photic zone euxinia at the P-T

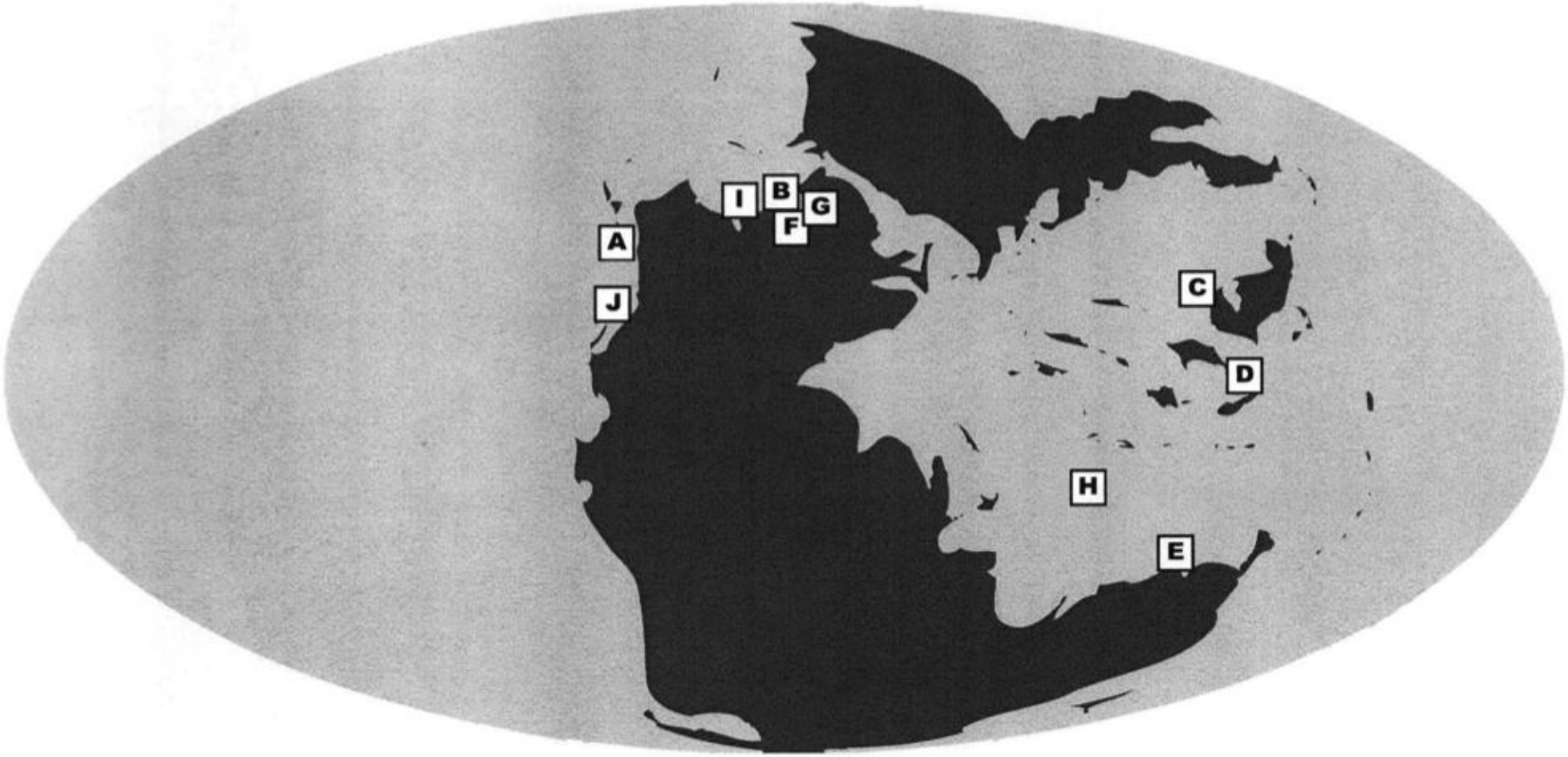


Figure 7.4 Global map from the Permian-Triassic boundary. Chlorobi-derived biomarkers have been identified in the sites noted. (a) Peace River, Canada. (b) Kap Stosch, Greenland. (c) Meishan, China. (d) Great Bank of Guizhou, China. (e) Perth Basin, Australia. (f) Kupfershiefer Basin, Germany. (g) Spitsbergen, Norway. (h) Tibet. (i) Blind Fiord, Canada. (j) Opal Creek, Canada. Map modified from Scotese Paleomap Project website.

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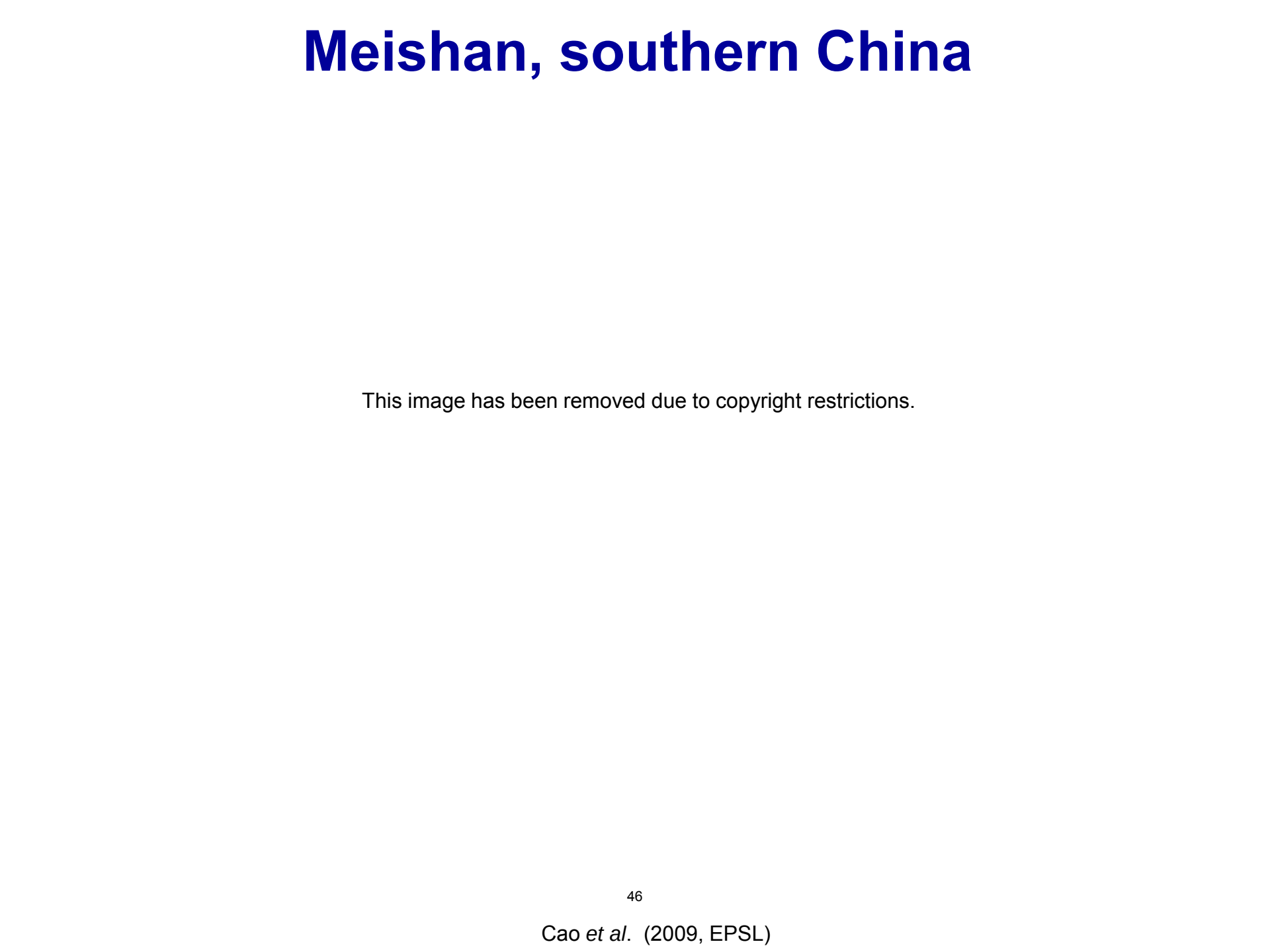
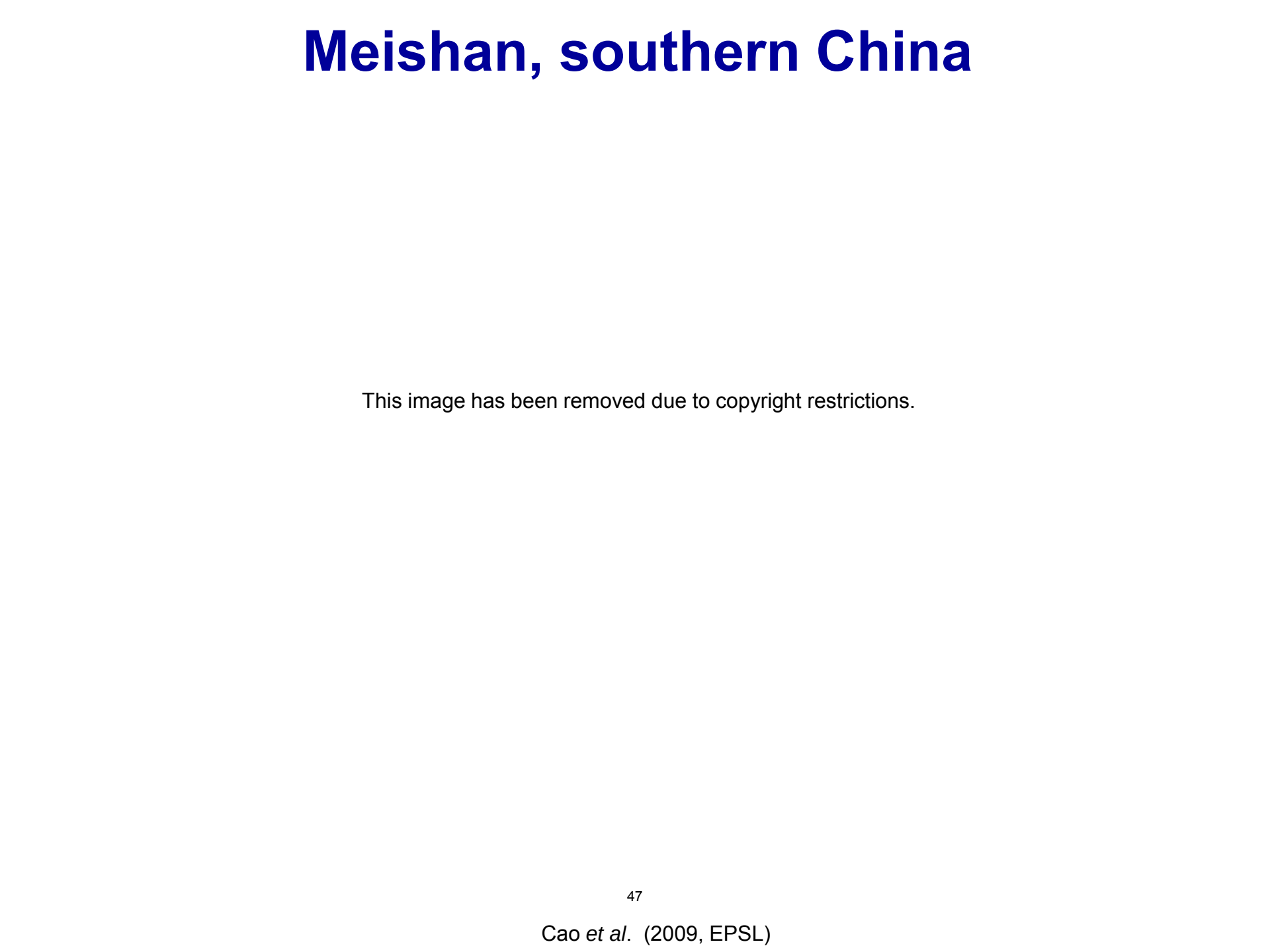
Meishan, southern China



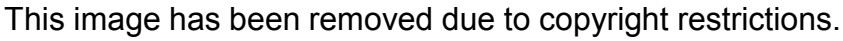
Cao *et al*. (2009, EPSL)

Meishan, southern China



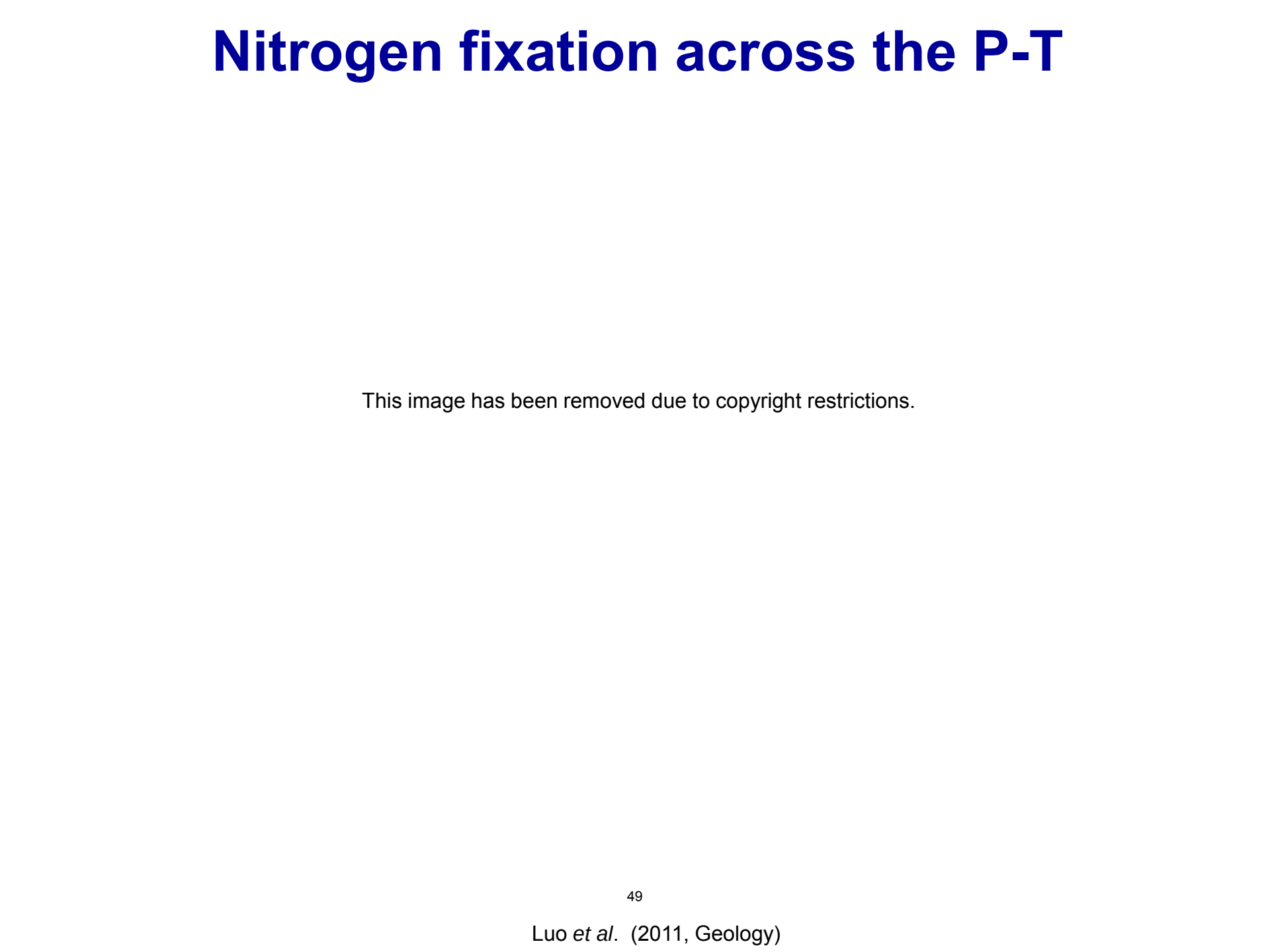
Cao *et al*. (2009, EPSL)

Meishan, southern China



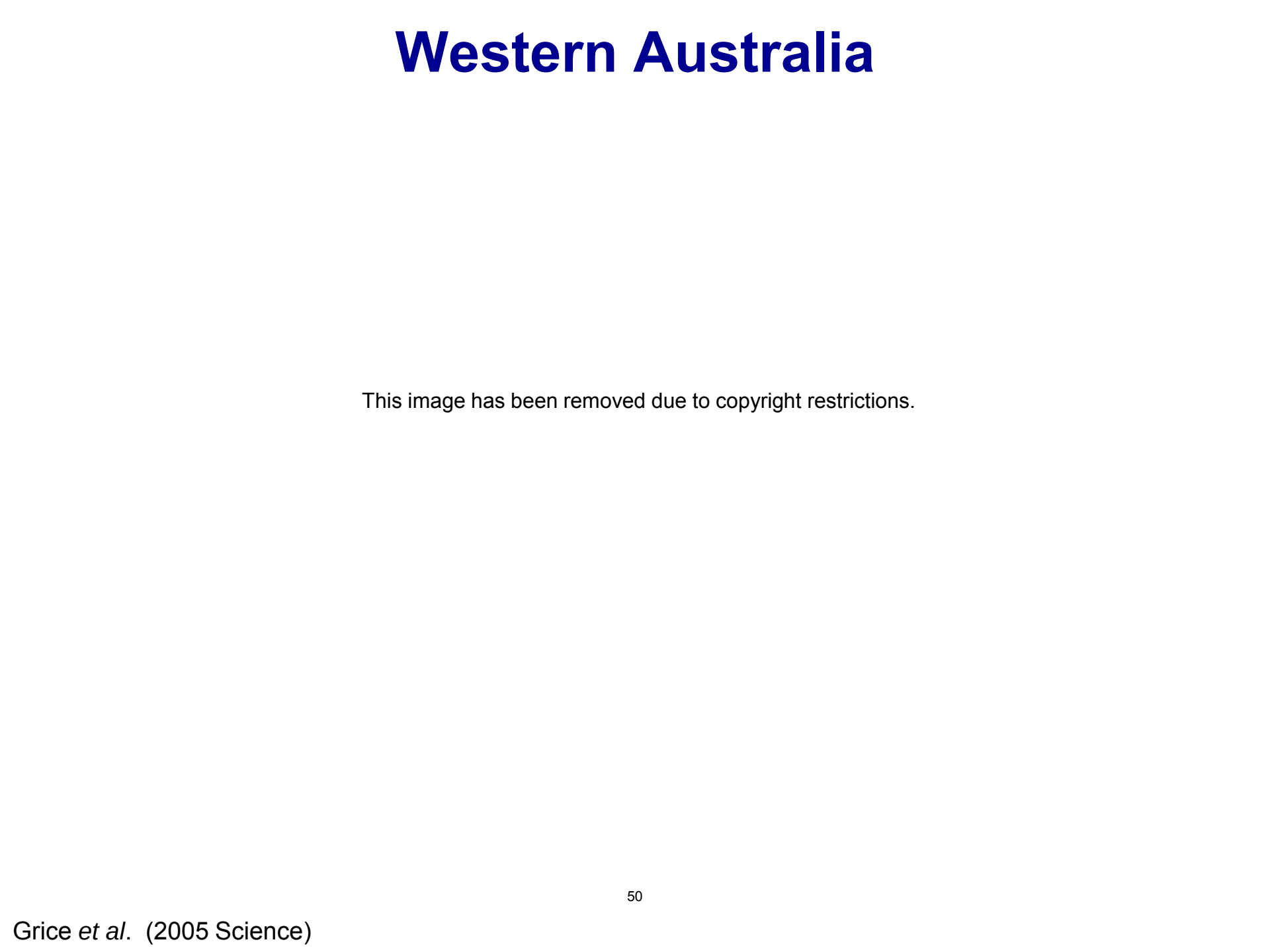
Cao *et al*. (2009, EPSL)

Nitrogen fixation across the P-T



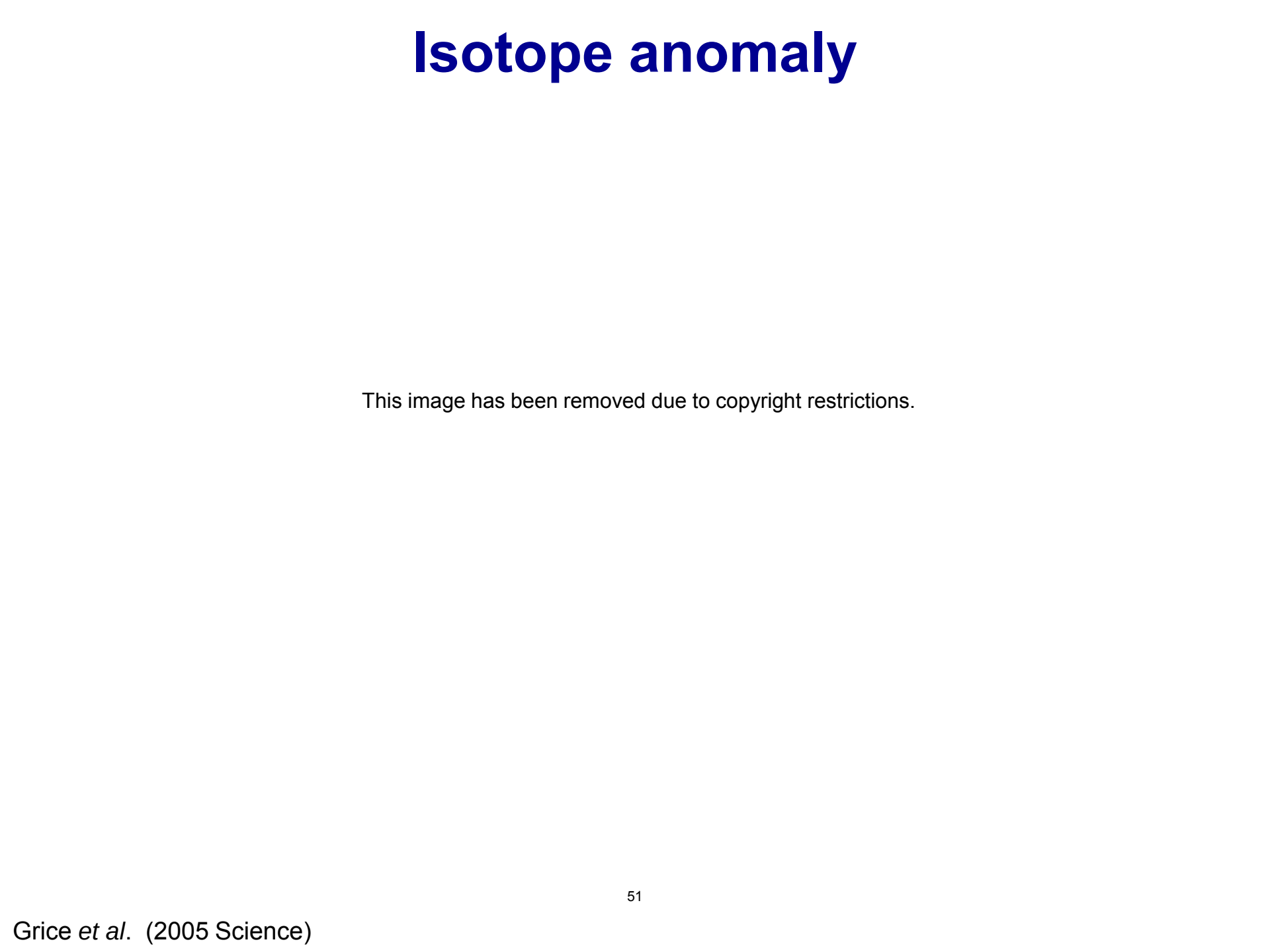
Luo *et al*. (2011, Geology)

Western Australia



Grice *et al*. (2005 Science)

Isotope anomaly



Grice *et al*. (2005 Science)

Isotope anomaly

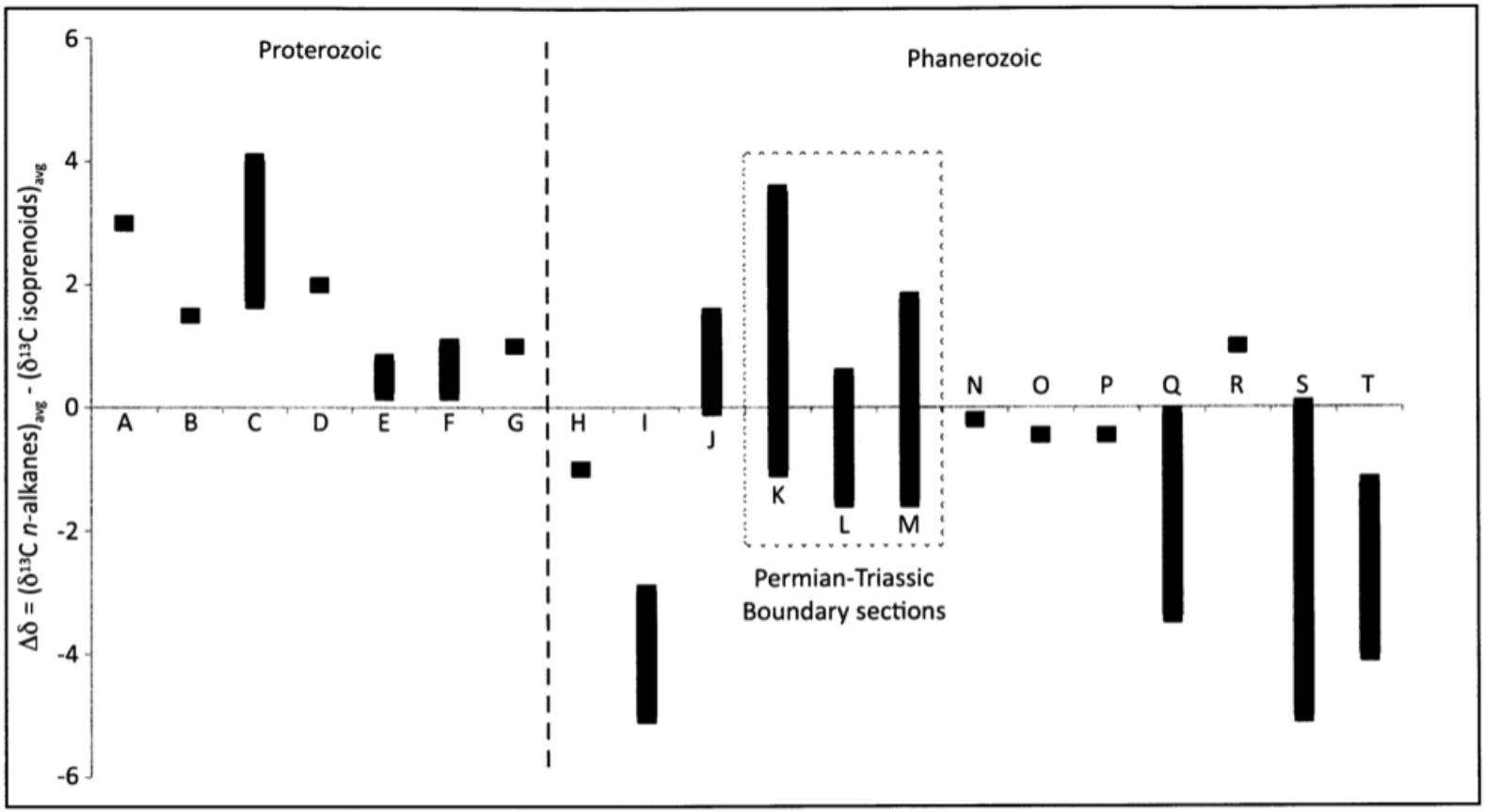


Figure 1.5 Enrichment of *n*-alkanes relative to isoprenoids from a range of environments. **K**, from Meishan, China and **L**, from Peace River Basin, Canada, were measurements made in this thesis from the Permian-Triassic boundary; **M**, from the Perth Basin, Australia (Grice et al. 2005) is also from this boundary. **J** and **R** are from Phanerozoic basins deposited beneath anoxic water columns. **A** Mount Bruce Supergroup, Pilbara Craton, Australia, 2.78-2.45Ga (Brocks et al. 2003). **B** Barney Creek Formation, McArthur Basin, Australia, 1690Ma; **C** Nonesuch Formation, USA, 1055Ma; **D** Walcott Member, Chuar Group, USA, 850Ma; **E** Bitter Springs Formation, Amadeus Basin, Australia, 800Ma; **F** Visingso Group, Sweeden, 775Ma (Logan et al. 1995). **G** South Oman Salt Basin, Buah Formation, Oman, 600Ma; **H** South Oman Salt Basin, Buah Formation, Oman, 547Ma (Kelly 2009). **I** Officer Basin, Australia, 510Ma; **J** Maquoketa Group, Illinois Basin, USA, 450Ma (Logan et al. 1995). **N** Paris Basin Shale, France, 180Ma; **O** West Hammersfest Basin, Barents Sea, 168Ma; **P** Guatamalan Carbonate, 100Ma (Bjoroy 1992). **Q** Eastern Llanos Baisn, Colombia, 65Ma (Cortez et al 2010). **R** Green River Shale, USA, 40Ma; **S** Baise Basin, Guanxi, China and Mulhouse Basin, Alsace, France, 28Ma (Logan et al. 1995). **T** Modern cultured algal lipids (Schouten et al. 1998).

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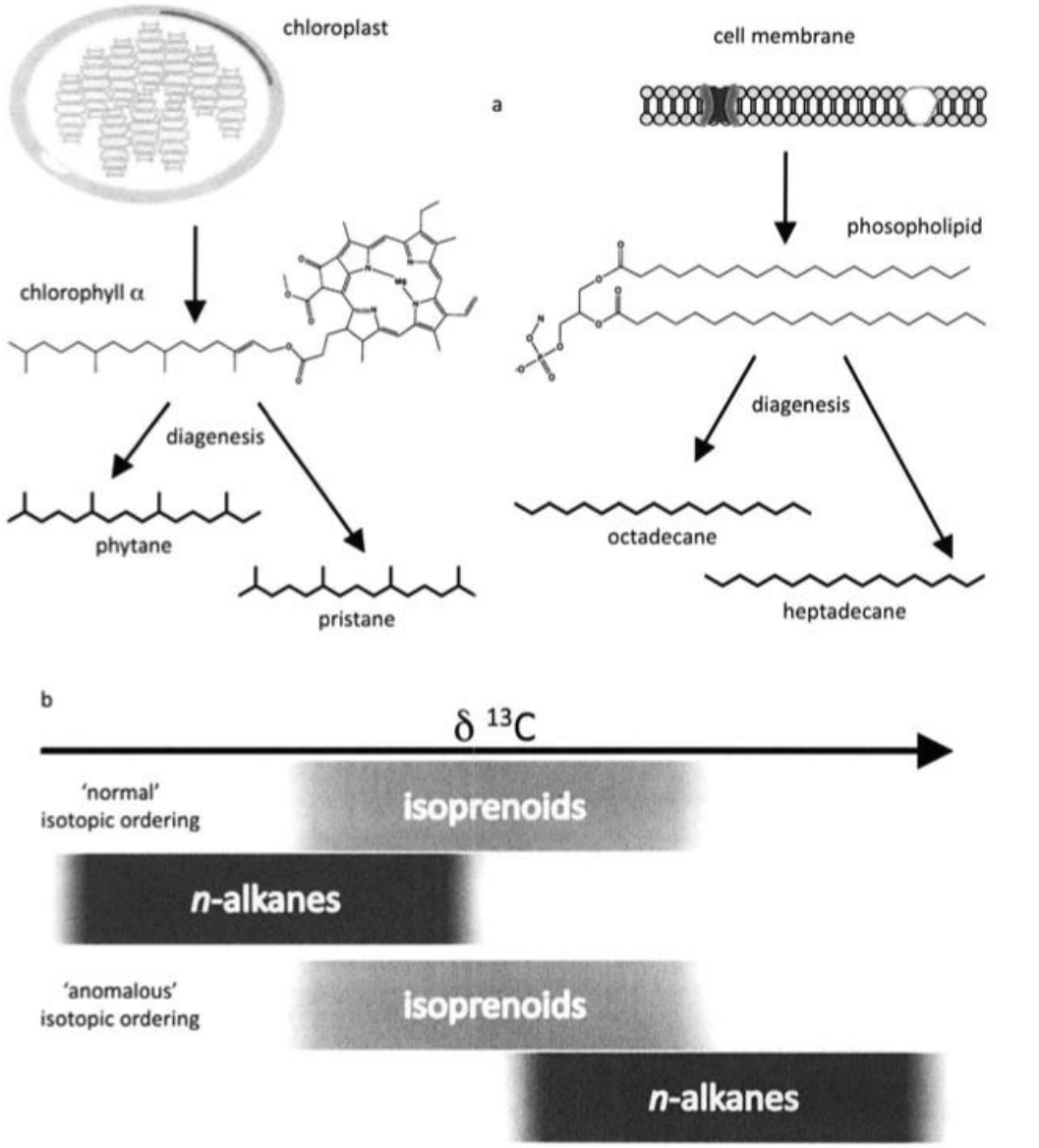
Isotope anomaly



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12.158 Molecular Biogeochemistry

Fall 2011